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1 Ziqian Jin has elected to forego publication of her paper in *The Pioneer Research Journal, Volume 6*, at this time because her paper is under consideration for publication in another research journal.

Foreword

The COVID-19 pandemic has reminded us that the rigorous and multidisciplinary pursuit of knowledge is vital to our survival and progress, and in a year defined by global upheaval where uncertainty abounds, The Sixth Edition of *The Pioneer Research Journal* offers a beacon of hope. The outstanding research in this volume reveals an inspiring determination among our brightest young scholars to pursue important lines of inquiry touching every aspect of our lives from cancer treatment to the very nature of knowledge itself.

This journal contains extraordinary scholarship by high school students from around the world, mentored by world class professors. In 2019, 658 young scholars drawn from high schools in 29 countries and regions were admitted to the Pioneer Research Program from an international pool of 1,751 applicants. Those admitted to the program participated in an international faculty-led cohort before working one-on-one with leading U.S. professors to conduct original undergraduate-level research in their area of interest. After a rigorous nomination and review process, 23 papers were selected for publication in this edition of *The Pioneer Research Journal*. The authors represented in this edition hail from Bangladesh, China, Estonia, India, South Korea, and the United States.

By conducting the program entirely online, Pioneer Academics has torn down barriers and has made undergraduate education available to promising young scholars from virtually every corner of the world. To ensure this opportunity is available to as many students as possible, Pioneer provided US \$555,136 in need-based scholarships to these scholars, again meeting 100% of demonstrated financial need and ensuring that we can fulfill our mission to remove obstacles to education.

The papers in this edition are exemplars of academic excellence. From an economic analysis of the military's role in present-day Egypt to a persuasive critique of Descartes' conclusions on the certainty of knowledge, the authors challenge us to question what we think we know and to seek out answers to the things we don't. This challenge is, quite simply, the bedrock of academic inquiry as we know it.

It is our goal to share this work widely, and so *The Pioneer Research Journal* is available in print and online at www.pioneeracademics.com and is distributed to select colleges, universities, and libraries worldwide.

I am so pleased to share it with you and hope you find it to be enjoyable and enlightening.

David G. Kamitsuka, Ph.D.
Dean of the College of Arts and Sciences
Oberlin College
Editor, The Pioneer Research Journal, Volume 6

Selection Process

To be nominated for publication in *The Pioneer Research Journal*, Pioneer scholar-authors first had to earn a letter grade of A- or higher from their professor mentor. Each professor mentor was invited to nominate one or two papers (depending on the number of scholars they mentored) that met the A/A- grading threshold and that, in their estimation, met the standards for publication in a journal of undergraduate-level research.

Following nomination, every paper was reviewed anonymously by a member of our 41-member committee of reviewers, each of whom is a professor with expertise in the subject areas of the papers they reviewed.

Contributing Readers scored the papers on a scale of 0–4 for four criteria: Engagement with Scholarship, Evidence and Analysis, Writing and Organization, and Scholarly Contribution. These four scores were then tallied, with a maximum score of 16. Papers with sub-scores of 0 in any category were disqualified from publication.

Once the above thresholds were met, the highest-scoring papers were provisionally selected. Upon notification, authors of provisionally selected papers received instructions from their paper's reviewer specifying the revisions required for meeting the standards of an undergraduate research journal. Every paper then underwent one more rigorous review by Pioneer's Writing Center tutors for editorial concerns and the authors were asked to make final revisions based on that review before their papers were finally published.

When all criteria were applied, only 4% of the papers generated in the 2019 Summer and Spring Terms were selected for publication in the Sixth Volume of *The Pioneer Research Journal*.

Sri Lanka Risk Analysis

Aditya Waddodagi

Author Background: *Aditya Waddodagi grew up in the United States and India and attended Greenwood High International School in Bangalore, India. His Pioneer research concentration was in the field of International Relations and titled “Political Risk and Prediction.”*

Editorial Note

In Political Risk and Prediction, risk methodologies and their applications to country and global case studies were investigated. A research paper was developed through an independent risk analysis on a chosen country case study. Relevant data points from open source information online were chosen and used to make an argument about the key risks—i.e., threats to stability—today and in the coming months/years for the country case study. This analysis was leveraged to make a recommendation to a real-world decision-maker (e.g., investor, government) in the conclusion.

Client

A major travel company in the Maldives known as Crown Tours Maldives.

Client Proposal

Crown Tours Maldives already operates in the Maldives, Mauritius, and Seychelles. The company is seeking to expand its operations to Sri Lanka by the end of 2019, seeing it as the next major tourism market. While the plans for this expansion commenced in the beginning of 2018, a number of important events have happened since then. In the face of the current climate in Sri Lanka, our client is concerned that the contemplated expansion has become too risky.

Introduction

Sri Lanka, a country of over 20 million, has faced a number of threats over its 72 years as an independent country. From simmering ethnic and religious

tensions, which have persisted since independence, to a civil war which killed over 150,000 people, Sri Lanka has experienced a particularly checkered history.¹ While progress has been made since the Civil War, especially economically and geopolitically, there are still several risks worth considering.

The key risks faced by Sri Lanka extend across four main areas, namely social, economic, political and geopolitical. Socially, for example, Sri Lanka faces heightened ethnic and religious tensions. Economically, the country faces growing public debt. Politically, Sri Lanka faces an unstable government. Geopolitically, it faces a growing dependence on China.

Through a detailed analysis of these risks, it can be determined that political risk is the greatest threat to Sri Lanka's stability. This is largely due to recent developments and uncertainty regarding the near future.

Initially, Sri Lanka seemed to have taken remarkable strides forward following the end of the Civil War in 2009, drawing widespread praise from the international community. This progress was made along a number of fronts. To begin with, institutions such as the judiciary became more legitimate, there was improved law and order, and there was increased stability in the government. In short, Sri Lanka seemed to represent a comeback story.

However, over the past few years the political stability associated with the Sri Lankan government has begun to falter. This is seen by the constitutional crisis which erupted in late 2018 amid tensions between President Sirisena and Prime Minister Wickremesinghe. Sri Lanka also experiences a number of other key political risks, such as rampant corruption and rising authoritarianism, which continue to plague the country.² Both the presidential and parliamentary elections are scheduled to be held in December of 2019.

Therefore, while Sri Lanka faces a number of key risks, such as social tensions and a growing dependence on China, developments like the constitutional crisis and upcoming elections make it likely that the next major flashpoint will be on the political front.

Time Horizon

The time horizon for this risk report is four months, with the analysis being highly relevant up until the presidential and parliamentary elections scheduled in December 2019.

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- 1 Bajoria, J. (2009). The Sri Lankan Conflict. Retrieved 11 September 2019, from <https://www.cfr.org/background/sri-lankan-conflict>
 - 2 Bemma, A. (2019). Is Sri Lanka using the Easter attacks to limit digital freedom? Sri Lanka bombings. *Al Jazeera*. Retrieved from <https://www.aljazeera.com/indepth/features/sri-lanka-easter-attacks-limit-digital-freedom-190707182546234.html>

Political Risk: High

Over the past year, the Sri Lankan political system appears to have experienced a marked decline in democracy, a clear contrast from the years of progress the country seemed to have made after the Sri Lankan Civil War. After defeating Rajapaksa in the 2015 presidential elections, Sirisena appointed Wickremesinghe as Prime Minister. However, over this time, the relationship between the two soured and in 2018 it was reported that Sirisena was looking to replace Wickremesinghe. This culminated in the constitutional crisis of late 2018, where Sirisena publicly declared Rajapaksa as the new Prime Minister. From this point onwards, political risk has heightened greatly.

At the state level, the constitutional crisis of late 2018 led to heightened tensions between President Sirisena and Prime Minister Rajapaksa, along with their respective party parliamentarians. This led to a lack of cooperation, communication, and trust between the two leaders.³ However, at the societal level, the effects of the constitutional crisis were seen to be far more intense. For example, on the fifth day of the political turmoil, thousands of supporters of Prime Minister Ranil Wickremesinghe protested in Colombo.⁴

To begin with, the outright declaration of a new Prime Minister in the political crisis of late 2018 showed President Sirisena's sheer disregard for the constitution. The involvement of the army in the political crisis, with numerous generals extending their support for President Sirisena, is also concerning. In an attempt to validate his decision, President Sirisena dissolved the parliament, a clear exploitation of his powers.

After Supreme Court involvement, Wickremesinghe was reinstated as Prime Minister. The tense relationship between President Sirisena and Prime Minister Wickremesinghe has led to the presence of an unstable and ineffective government. This, in turn, has had a number of devastating consequences. For instance, the lack of discourse between the President and the Prime Minister contributed to the failure to detect the Easter Sunday attacks.⁵ Prime Minister Wickremesinghe's party also does not have the

3 (n.d.). Economic Studies and Country Risks. Retrieved from <https://www.coface.com/Economic-Studies-and-Country-Risks/Sri-Lanka>

4 Aneez, S. (2018, October 30). Supporters of ousted PM protest as Sri Lanka gripped by political crisis. Retrieved from <https://www.reuters.com/article/sri-lanka-politics/supporters-of-ousted-pm-protest-as-sri-lanka-gripped-by-political-crisis-idUSKCN1N412Y>

5 (2019). Political Risk Map 2019. Retrieved from <https://www.marsh.com/us/campaigns/political-risk-map-2019.html>

required two-third majority to implement any of the planned legislation in parliament. This has led to further political gridlock and has added to political risk.⁶

Since 2015, President Sirisena has shown increasingly authoritarian tendencies. For example, he is evaluating avenues to reverse the 2015 amendments to the constitution that curbed the powers of the executive. This would allow the President to oust the Prime Minister at will, among other abilities. This, therefore, poses a political risk and indicates a rise of authoritarianism in the country.⁷

Sri Lanka is ranked 89/180 in Transparency International's Corruption Index 2018, with a score of 38/100.⁸ The unavailability of government finance reports relating to the Hambantota port clearly demonstrates this lack of transparency. In addition, allegations of corruption are repeatedly in the news. For example, during the political crisis of late 2018, lawmakers claimed they were offered upwards of \$2 million to switch party allegiance.⁹ This poses a chronic risk of weakening democratic institutions and political rights.

However, the resilience of Sri Lanka's political system shined through during the constitutional crisis of late 2018. Though it should have never come to the point where Sirisena sacked Wickremesinghe without any parliamentary inquiry, the rejection of Sirisena's actions by the Supreme Court highlighted its independence.

Future Outlook—in the coming months, the Sri Lankan government will remain at a heightened state of risk. As both the presidential and parliamentary elections are scheduled to be held in December 2019, there is the potential for a change in both the president and the prime minister. It is unclear whether President Sirisena will compete in the upcoming elections.¹⁰ This combination of factors highlights the uncertainty faced in the political system and may either intensify or calm the infighting present in Sri Lanka's government. However, the chronic political risks experienced by Sri Lanka are likely to remain.

6 (n.d.). Economic Studies and Country Risks. Retrieved from <https://www.coface.com/Economic-Studies-and-Country-Risks/Sri-Lanka>

7 Bemma, A. (2019). Is Sri Lanka using the Easter attacks to limit digital freedom? Retrieved 11 September 2019, from <https://www.aljazeera.com/indepth/features/sri-lanka-easter-attacks-limit-digital-freedom-190707182546234.html>

8 (n.d.). Sri Lanka. Retrieved from <https://www.transparency.org/country/LKA>

9 Bastians, D., & Gettleman, J. (2018, November 2). Bribery Accusations Deepen Turmoil in Sri Lanka. Retrieved from <https://www.nytimes.com/2018/11/02/world/asia/sri-lanka-prime-minister-bribery-crisis.html>

10 (2019, July 11). Who is running for President? Retrieved from <http://www.dailynews.lk/2019/07/11/features/190805/who-running-president>

Possible Shock Event—possible shock events which may occur in the coming months include a collapse of the current government due to an escalation of the conflict between President Sirisena and Prime Minister Wickremesinghe, or a large citizen led movement against government inaction.

Social Risk: High

In light of the recent Easter Sunday attacks on the 21st of April 2019, the social risk experienced by Sri Lanka is especially high. The attacks, carried out by jihadists, have led to a flaring of religious tensions between the Sinhala Buddhist majority and Muslim minority.¹¹

For example, following the attacks, when large scale meetings were prohibited, the government turned a blind eye to large scale meetings of the Bodu Bala Sena (BBS), a leading Sinhala Buddhist extremist group.¹² This increased activity of Sinhala extremist groups after the Easter Sunday attacks has contributed to a marked increase in social tensions at the state level as well. For example, following the attacks, all nine of the country's Muslim ministers and two Muslim provincial governors resigned under pressure from Athuraliye Rathana, a prominent Buddhist monk and presidential adviser, who accused them of having links to the Easter Sunday attack militants.¹³ The influence held by Buddhist religious leaders in Sri Lankan politics further poses a significant risk.

However, deep social fissures along ethnic and religious lines have plagued Sri Lanka for decades. Ethnic fissures first arose during the period of British colonialism. After decades of simmering, these tensions finally culminated in the Sri Lankan Civil War (1983–2009) which, over the span of 20 years, led to the deaths of hundreds of thousands of civilians and soldiers. The Rajapaksa government was accused of gross human rights violations during the War. The failure to prosecute the accused has led to heightened ethnic tensions.¹⁴

11 Sen, J. (2019). Sri Lanka attacks put the country's Muslims at risk. Retrieved 11 September 2019, from <https://dailybrief.oxan.com/Analysis/DB243381/Sri-Lanka-attacks-put-the-countrys-Muslims-at-risk>

12 Al Maena, T. (2019). Blaming Saudi Arabia won't help Sri Lanka—Extremist Buddhist monks are way off the mark, and also overlooks Riyadh's financial aid *Asian Tribune*. Retrieved 11 September 2019, from <http://www.asiantribune.com/node/92906>.

13 Chaudhary, S. (2019). How to Fight ISIS in Sri Lanka. Retrieved 11 September 2019, from <https://prospect.org/article/how-fight-isis-sri-lanka>

14 Venugopal, R. (2019). Sinhala Nationalism. Retrieved 11 September 2019, from https://www.cambridge.org/core/services/aop-cambridge-core/content/view/0DEF9D0367D77E0190D9D28F865277F3/9781108553414c2_p20-44_CBO.pdf/sinhala_nationalism.pdf

The threat posed by social tensions has become especially volatile over the past few years. This is largely because of the emerging role of social media in the dispersal of information. Following the Easter Sunday attacks, for instance, rumors began to spread through social media platforms, often filled with hate speech, inciting extensive panic and hysteria in the population. The attacks further helped embolden Sinhala extremists in spreading hatred. The Sri Lankan government responded to this by temporarily blocking access to a number of social media platforms. However, the perceived efforts by the government to mitigate hate speech and misinformation have been to no avail, according to the Center for Policy Alternatives, as no Sri Lankan has been prosecuted for perpetrating hate speech or hate crimes under the country's laws.¹⁵

The crux of the social risk in Sri Lanka is therefore seen to be Sinhalese nationalism and the failure of government institutions.¹⁶ The political system, following the Sri Lankan Civil War, has been fueled by a majority-minority complex following a global trend in democratic governments. This has led to the two dominant Sinhalese parties, namely the Sri Lanka Freedom Party and the United National Party, competing with each other in an effort to appeal to Buddhist voters, in the process disregarding the Tamil and Muslim minorities. While the 2015 elections provided an opportunity to address the tensions stemming from the Sri Lankan Civil War, this was avoided by the two dominant Sinhalese parties, leading to the collapse of the reformist agenda.¹⁷ The failure of government institutions is seen through the failure to prosecute those accused of hate speech, the failure to contain communal violence, and the widespread arbitrary arrests of often innocent citizens.¹⁸

Future Outlook—religious tensions, with regards to the Muslim minority, are unlikely to decrease over the coming months. The targeting of the Muslim minority has become a chronic phenomenon following the end of the Sri

15 Bemma, A. (2019). Is Sri Lanka using the Easter attacks to limit digital freedom? Retrieved 11 September 2019, from <https://www.aljazeera.com/indepth/features/sri-lanka-easter-attacks-limit-digital-freedom-190707182546234.html>

16 Venugopal, R. (2019). Sinhala Nationalism. Retrieved 11 September 2019, from https://www.cambridge.org/core/services/aop-cambridge-core/content/view/0DEF9D0367D77E0190D9D28F865277F3/9781108553414c2_p20-44_CBO.pdf/sinhala_nationalism.pdf

17 Staniland, P. (2019). The Future of Democracy in South Asia. Retrieved 11 September 2019, from <https://www.foreignaffairs.com/articles/south-asia/2019-01-04/future-democracy-south-asia>

18 Sri Lanka: Muslims Face Threats, Attacks. (2019). Retrieved 11 September 2019, from <https://www.hrw.org/news/2019/07/04/sri-lanka-muslims-face-threats-attacks>

Lankan Civil War. With Tamils no longer being perceived as a serious threat, Sinhalese leaders have begun to shift their focus to Muslims. For example, in 2018, anti-Muslim riots broke out stemming from a rumor that Muslim restaurant owners, most notably A.L Farsith, intentionally attempted to sterilize Sinhalese women.¹⁹ The 2020 government elections are likely to play a major role in dictating ethnic tensions between the Sinhalese and the Tamils. There may be a rise in tensions if Rajapaksa comes to power, while tensions may stay constant if Wickremesinghe remains in power.

Possible Shock Event—a possible shock event which may occur in the coming months is a large-scale riot by Muslims in response to the injustices they feel they have endured.

Economic Risk: Moderate

Despite an improvement in economic measures following the Sri Lankan Civil War, the economy still experiences heightened risk. To begin with, Sri Lanka faces a growing crisis with government debt having risen to 79% of the country's GDP, leading to devastating effects.²⁰ Government debt has led to a significant cut in government spending on essential programs, primarily due to a lack of foreign currency inflows. For example, foreign investments in Sri Lanka have remained below 2% of GDP (compared to 6.3% of GDP in Vietnam in 2017) over the past twenty years.²¹

Sri Lanka faces a lack of diversity in FDI, as new investments in the past few years have been predominantly infrastructure-oriented. This is seen by the use of Chinese loans to fund the construction of major projects such as the Hambantota port.²² This combination of factors has led to a downgrade in credit ratings in November and December 2018 by Fitch (B), Moody's (B) and S&P (B2).²³

19 Tension in Ampara after fake 'sterilization pills' controversy. (2019). Retrieved 11 September 2019, from <http://www.sundayobserver.lk/2018/03/04/news/tension-ampara-after-fake-sterilization-pills-controversy>

20 Sen, J. (2019). Sri Lanka—Oxford Analytica Daily Brief. Retrieved 11 September 2019, from <https://dailybrief.oxan.com/Regions/Asia-Pacific/Sri-Lanka>

21 Fernando, D. (2019). Sri Lankan Economy—The Way Forward. Retrieved 11 September 2019, from http://www.apbsrilanka.org/wp-content/uploads/2019/01/2018_30th_conv_a_5_Dr.Shan_Fernando.pdf

22 Moramudali, U. (2019). Is Sri Lanka Really a Victim of China's 'Debt Trap'?. Retrieved 11 September 2019, from <https://thediplomat.com/2019/05/is-sri-lanka-really-a-victim-of-chinas-debt-trap/>

23 Overseas Business Risk—Sri Lanka. (2019). Retrieved 11 September 2019, from <https://www.gov.uk/government/publications/overseas-business-risk-sri-lanka/overseas-business-risk-sri-lanka>

Furthermore, Sri Lanka is ranked 100th out of 190 economies in the Ease of Doing Business Index 2019 (published by the World Bank/IFC), showing a major reason for the lack of FDI. Critical challenges experienced by Sri Lanka on this front include weak land administration, political uncertainty, policy fragmentation, frequent policy changes and slow policy implementation. However, in the coming months, improvements are expected in the areas of starting a business, property registration, and construction permits, as the government recovers from the Easter Attacks.²⁴

Sri Lanka also faces slowing economic growth, which has been caused by a number of factors such as currency depreciation, tight monetary policy, a growing trade deficit, and stagnant worker remittances.²⁵ The Easter Sunday attacks have also played a significant role by greatly affecting the tourism industry, a major sector in the Sri Lankan economy. The constitutional crisis towards the end of 2018 affected investor confidence, and has also contributed to the slowing economic growth. This is highlighted through a comparison with other South Asian countries. For example, while Sri Lanka's GDP growth rate decreased from 3.42% in 2017 to 3.21% in 2018, Bangladesh's GDP growth rate increased from 7.28% in 2017 to 7.86% in 2018.²⁶

Income inequality continues to remain stubbornly high and has remained at the same level for more than four decades.²⁷ While the richest 20% enjoy more than half the total household income in the country, the poorest 20% account for only 5% of that income. This income inequality is further seen to be along geographical and social lines. For example, in the Colombo district, located in the Sinhala dominated south of the country, 41% of the households are in the "richest group", with a monthly income of Rs. 81,372 or more. On the other hand, in the Mullaitivu district, located in the Tamil dominated north of the country, 71.6% of households fall into the 'poorest group', with a monthly household income of less than Rs. 36,500. These statistics demonstrate the clear lack of effective policy implemented by the government,

24 Overseas Business Risk—Sri Lanka. (2019). Retrieved 11 September 2019, from <https://www.gov.uk/government/publications/overseas-business-risk-sri-lanka/overseas-business-risk-sri-lanka>

25 Overview. (2019). Retrieved 11 September 2019, from <https://www.worldbank.org/en/country/srilanka/overview>

26 South Asia: Sri Lanka—The World Factbook—Central Intelligence Agency. (2019). Retrieved 11 September 2019, from <https://www.cia.gov/library/publications/the-world-factbook/geos/ce.html>

27 (2019). Political Risk Map 2019. Retrieved from <https://www.marsh.com/us/campaigns/political-risk-map-2019.html>

especially after the Sri Lankan Civil War.²⁸ The government has, nevertheless, made considerable progress through its introduction of the Samurdhi program. The main goal of this program is to reduce poverty through development based on public participation.²⁹ While poverty rates steeply declined from 8.9% in 2010 to 4.1% in 2016, there is still headway to be made.³⁰

Over the past few years, however, Sri Lanka has made notable strides forward on the economic front. For example, the country is working towards improving trade relations with other countries and is in the process of negotiating free trade agreements with countries in the region, including India, China, Bangladesh, Malaysia, South Korea and Japan.

Future Outlook—in the coming months, it is hoped that key infrastructure development, such as the new Colombo Port City, which the government is hoping will become a regional financial hub, will bring in significant investment. This may help mitigate the effects of a debt crisis. However, in the near future high public debt and political uncertainty will likely hinder economic development. Sri Lanka's GDP growth rate is expected to slightly increase from 3.5% in 2019 to 3.6% in 2020, however, this will still be significantly lower than the GDP growth rate of 4.5% achieved in 2016.³¹

Possible Shock Event—a possible shock event which may occur in the coming months is a deep economic recession. The Sri Lankan debt crisis, along with global trends like the U.S.-China tariff war, increase the likelihood of such an event happening.³²

Geopolitical Risk: Low

The geopolitical risk experienced by Sri Lanka is not as heightened when compared to the other risks. However, the country still faces some potentially serious sources of instability.

To begin with, heavy financial borrowing from China has led to a steady buildup of Sri Lankan debt, as seen by the debt-heavy construction of the

28 Nanayakkara, W. (2018, December 27). A Balancing Act: Can Sri Lanka Overcome Regional Income Inequalities? Retrieved from <http://www.ips.lk/talkingeconomics/2018/12/27/a-balancing-act-can-sri-lanka-overcome-regional-income-inequalities/>

29 Irigoyen, C. (2017, May 30). The Samurdhi Programme in Sri Lanka. Retrieved from <https://www.centreforpublicimpact.org/case-study/samurdhi-programme-sri-lanka/>

30 Elmer. (2019, May 6). Poverty in Sri Lanka. Retrieved from <https://www.adb.org/countries/sri-lanka/poverty>

31 Sri Lanka. (n.d.). Retrieved from <https://data.worldbank.org/country/sri-lanka>

32 Inman, P. (2019, August 25). Is a global recession coming? Here are seven warning signs. Retrieved from <https://www.theguardian.com/uk-news/2019/aug/25/is-a-global-recession-coming-here-are-seven-warning-signs>

Hambantota Port. Some U.S. officials say that this is a strategy devised by China to trap countries in debt to give it greater sway and advance its military aims. If so, this poses a geopolitical risk due to the growing influence of China in domestic and foreign policy. Sri Lanka's heavy Chinese borrowing may further pose a threat to Sri Lankan sovereignty. An increased Chinese presence has been clearly seen over the past few years. For example, there have been multiple sightings of Chinese military submarines in the waters of Sri Lanka. Sources report that President Sirisena was uninformed of these submarine visits beforehand.³³

In addition, Sri Lanka faces a complex relationship between India and China. It is important for Sri Lanka to maintain a delicate balance in the relations between these two countries to prevent the antagonization of the other. The Sri Lankan government is in the midst of a proxy conflict, with Prime Minister Wickremesinghe being supported by the Indian government, and President Sirisena being supported by the Chinese government.³⁴

Sri Lanka has experienced chronic geopolitical risk as a result of alleged human rights violations during the Sri Lankan Civil War. While there was immense Western pressure towards the Rajapaksa government to investigate the alleged crimes, this pressure has settled following the election of the West-friendly Sirisena government. However, Sri Lanka still occasionally faces criticism for its failure to address past injustices.

International terrorism also poses a significant threat to stability. Having only entered national discourse after the Easter Sunday attacks, the absence of a legal framework to address this risk is now acknowledged. The Prevention of Terrorism Act, an outdated counterterrorism law designed to prosecute internal threats rather than foreign ones, has proven to be ineffective in addressing the threats experienced as a result of ISIS and other terrorist organizations. As Sri Lankan Prime Minister Ranil Wickremesinghe said after the Easter attacks: "we have no laws which enable us to take into custody people who join foreign terrorist groups. We can take those who are, who belong to terrorist groups operating in Sri Lanka."³⁵ Therefore, until a revised counterterrorism law is implemented by the Sri Lankan government, international terrorism represents a serious geopolitical risk.

33 Bellman, E. (2019, January 29). Sri Lanka, Deep in Debt, Turns Increasingly to China for Loans. Retrieved from <https://www.wsj.com/articles/sri-lanka-deep-in-debt-turns-increasingly-to-china-for-loans-11548774001>

34 (2019). Political Risk Map 2019. Retrieved from <https://www.marsh.com/us/campaigns/political-risk-map-2019.html>

35 Chaudhary, S. (2019). How to Fight ISIS in Sri Lanka. Retrieved 11 September 2019, from <https://prospect.org/article/how-fight-isis-sri-lanka>

Future Outlook—the geopolitical risk faced by Sri Lanka due to the dynamics between India and China is likely to continue into the near future. However, further down the line, Sri Lanka is likely to stray closer towards China, as seen by present day indicators.

Possible Shock Event—a possible shock event which may occur in the coming months is a terrorist attack influenced by an international terrorism organization. The “success” of the Easter Sunday attacks may embolden radical Muslims to follow. The lack of effective legislation to tackle foreign terrorist threats increases the likelihood of such an event.

Recommendation

Crown Tours Maldives faces a high level of risk if it decides to expand into Sri Lanka in the coming months. On the political front, future government instability due to infighting may hinder the company’s ability to predict future policies. On the societal front, occasional outbursts of sectarian violence may jeopardize the safety of the company’s customers. A related risk is observed on the geopolitical front. The Easter Sunday attacks of April 2019 heightened the threat of a future terrorist attack influenced by an international terrorist organization. In the aforementioned attacks, the terrorists targeted Christians and Westerners in order to generate the greatest international impact. As the customers of this luxury tourist company are likely to be of such a background, if the trend continues, they are likely to face considerable imperilment. However, the economic front is likely the most relevant to Crown Tours Maldives. As seen by Sri Lanka’s current economic situation, the company would face difficulties in doing business due to policy fragmentation, slow policy implementation, and weak land administration, along with a slowdown in the tourism industry. With the country facing a debt crisis, there is also a heightened risk of an economic recession.

As Crown Tours Maldives is not necessarily restricted by a tight time schedule, the company should consider expanding into Sri Lanka later in 2020. By this time, uncertainty associated with the upcoming elections is likely to abate. In addition, the tourism industry is likely to recover from the effects of the Easter Sunday attacks. Essentially, while certain risks, such as sectarian violence, are likely to remain well into 2020, many other risks are likely to lessen. An expansion in 2020 would therefore be a far safer alternative.

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The Ceiling of the Cappella Palatina

Norman Sicily's Diversity and Artistic Style Under Roger II

Annalise Selden

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Abstract

This paper explores the diversity present in the culture of Norman Sicily under King Roger II and how different areas around the Mediterranean Sea exerted their influence on the identity of Sicily in medieval times. The ceiling of the Cappella Palatina, the royal chapel of the Norman Palace in Palermo, serves as a window into the different identities—and both religious and cultural traditions—present in the Sicilian population. The figural depictions and the vegetal, geometric, and scriptural decorations in the ceiling, painted on the muqarnas, display the multiethnic history of Sicily before Roger II's rule, as well as the web of diplomatic and trade connections in the Mediterranean world that centered on Sicily.

In order to assess Roger's deliberate acknowledgment of Sicily's diverse culture, the study examines the visual vocabulary of the ceiling decoration. The ornate painted muqarnas ceiling exemplifies artistic styles tied to different religions and reveals the connections maintained by Roger with other governments through the content and languages in the ceiling painting. Alongside the artistic assessment is contextualization of where specific decorative features originated and their meaning, both within the original culture and in Norman Sicilian art.

The ceiling contains elements of Byzantine, Arab, Muslim Spanish, Romanesque, and Fatimid Egyptian art. Whether these different decorative characteristics were adopted from legacies in Sicily itself, from general trade, or from royal connections varies between each region, including combinations of all factors. The variety of cultural content in the paintings also works in conjunction to create a strong royal image of Roger II and strengthen his position in a kingship that he created himself.

The close examination of specific decorative elements in the ceiling of the Cappella Palatina illuminates how different images from various cultures in Europe, Africa, and the Middle East converged to characterize the art of Norman Sicily. Rather than removing the traces of diversity in Sicily, Roger II intentionally incorporated visually appealing decorative elements from backgrounds different from his own. Though the Cappella Palatina is ultimately a Christian space for a Norman king, Roger emphasizes the diversity of his kingdom to legitimize his authority over Sicily.

Introduction

During medieval times, specifically in the 11th and 12th centuries, the island of Sicily harbored remarkable heterogeneity, and its government fostered the coexistence of cultures from various corners of the Mediterranean and the surrounding areas. Far from isolated, Sicily's location prompted its role as a Mediterranean hub where trade flowed both in and out frequently due to its easy accessibility for sea-faring peoples.¹ Throughout its history, exploration, trade, and diplomacy facilitated the convergence of the traditions of different Mediterranean peoples on this one point in the region. The Normans who ruled Sicily in the 12th century nurtured great artistic representations of Sicily's rich history, and the interlocking, yet distinct, cultural communities living there at the time. Norman dukes from the Hauteville family succeeded a 200-year period of Muslim occupation that infused the area with Islamic artistic styles and cultural practices. In addition, there were hundreds of years of previous occupations by Greeks, Romans, and Byzantines.² Though not much

1 Luigi Giacobbe, et al. "Sicily," Grove Art Online, 2003, last modified June 2, 2011, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T078500>.

2 Martin Kauffmann, "Hauteville, House of family," Grove Art Online, 2003, last modified July 9, 2012, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T036942>.

survives of the Sicily dominated by Islam, its influence can be found in later Norman architecture and its decoration, which drew from the lavish style they saw on the island. This lasting legacy of Norman Muslims was adopted into the royally sponsored art and architecture of Roger II, and other Norman kings afterwards.

The ceiling of the Norman Sicilian royal chapel, the Cappella Palatina, built and decorated between 1130 and 1183, particularly embodies Roger II's inclusivity and acknowledgment of both Sicily's past and present under his rule.³ (Figure 1) While one can initially recognize the ceiling's Islamic style due to its use of muqarnas, the painted decoration contains nuances connecting to other artistic traditions from areas such as Spain and the Byzantine Empire.

(Fig. 2) In order to secure support and ensure a stable future with the position he created for himself as king of Sicily, Roger acknowledged that his kingdom had been dominated by other cultures and that its contemporary culture hosted diverse groups from around the Mediterranean.⁴



Figure 1.
1131—1143. Cappella Palatina di Palermo,
View of the central dome and apse
mosaics. [https://library.artstor.org/asset/
CANYONLIGHTS_DB_10312430843](https://library.artstor.org/asset/CANYONLIGHTS_DB_10312430843).

Historical Background

Some of the first conquerors to leave their mark on the island of Sicily were Greeks, with occupations that commenced in the 700s BCE, beginning on the eastern side of the island before diffusing throughout Sicily.⁵ North African settlers began to inhabit Western Sicily during the same period as

³ Jean Castex, *Architecture of Italy*, (Westport: ABC-CLIO, LLC, 2008), 91, ProQuest Ebook Central.

⁴ Giacobbe, "Sicily."

⁵ Giacobbe, "Sicily."

the Greeks.⁶ These colonies persisted until the Romans partially incorporated Sicily into their empire in 270 BC, granting citizenship to all Sicilians under the Roman Republic.⁷ Sicily under the Romans became a multilingual society early on with both Greek and Latin serving as administrative languages, but Greek was the language of the common people due to the Greek occupations and origins of people living there at the time. Greek resurfaced once again as the predominant language under the control of the Byzantine Empire, from 535 to 827. While Sicily was under the control of the Byzantines, there continued to be perpetually increasing diversity as migrants from across the Mediterranean settled on the island.⁸



Figure 2.

1130–43. Palermo, Palatine Chapel, Interior, Ceiling. architecture. https://library.artstor.org/asset/SCALA_ARCHIVES_1039931508.

Following the period of Byzantine control over Sicily, Muslims conquered the island over a period lasting from around 830 to 900 and incorporated it into their empire, exerting rich commercial and cultural influence.⁹ During this time, Sicily was established as an intermediary point in Mediterranean networks of exchange, with both trade and human beings flowing through the island and leaving cultural imprints through goods and permanent residencies. The Normans later fostered the diversity of Sicily by allowing continued heterogeneity among the diverse local population during their rule.¹⁰

6 Alexander Metcalfe, *Muslims and Christians in Norman Sicily: Arabic-Speakers and the End of Islam*, (London: Routledge, 2002), 3–4, ProQuest Ebook Central.

7 Jeremy Johns, *Arabic Administration in Norman Sicily: The Royal Diwan*, Cambridge Studies in Islamic Civilization, (Cambridge: Cambridge University Press, 2002), 12, <https://doi.org/10.1017/CBO9780511550386>.

8 Metcalfe, *Muslims and Christians in Norman Sicily: Arabic-Speakers and the End of Islam*, (London: Routledge, 2002), 7–8.

9 Giacobbe, “Sicily.”

10 Helen M. Hills, et al. “Palermo,” Grove Art Online, 2003, last modified September 22, 2014, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T064825>.

Though Muslims in Sicily came from the Middle East and near the Byzantine Empire, they also hailed from Egypt, North Africa, and Islamic Spain.¹¹

Despite the apparent uniformity of single government-sanctioned languages, there were a variety of Latin and Greek dialects scattered throughout up to the onset of the Muslim occupation of Sicily. Historian of Norman Sicily Alexander Metcalfe establishes that the culture of Sicily, even up to 600 years prior to its annexation by Rome, was extremely dynamic due to trade, movement, and immigration all around the Mediterranean. Roman, Byzantine, and Muslim administrations ruling over Sicily did declare official languages but the diversity of the population of Sicily maintained linguistic diversity. Variation of language was especially tolerated under the Normans.¹²

Sicily lies almost directly in the center of the Mediterranean Sea, in close proximity to both North Africa and Italy, as well as in the path between the western areas of Spain, France and Greece, the Byzantine Empire, the Arabian Peninsula, and Egypt in the east. Its central orientation translates to Sicily being the ideal place for exchange, a point at which trade routes converge and bring wealth, goods, and traditions. Scholars note Sicily for its function as a midpoint for pilgrims on their way to the Holy Land from Western Europe.¹³

Trade with other kingdoms and areas facilitated the vast wealth of the Norman kings and of Sicily itself. Perhaps of greater interest, the importation of luxury goods influenced the styles of art developed by the Normans for their buildings, as the characteristic motifs and styles from Mediterranean cultures were conveyed in their portable objects as well. Textiles in particular should be noted for their influence, especially within the context of what scholars classify as the Islamic elements of Norman art. These high-end, luxury purchases displayed some of the most complex and intricate work by Islamic cultures at the time. Precious textiles from Muslim Spain and “gifts and rarities” from the Moroccan Almohads have been identified as flowing into Sicily to the Norman kings in exchange for local valuable goods.¹⁴

11 Lev Kapitaikin, “The Daughter of al-Andalus’: Interrelations between Norman Sicily and the Muslim West,” 2013, 113–134, <https://doi.org/10.1080/09503110.2013.767019>.

12 Metcalfe, *Muslims and Christians in Norman Sicily: Arabic-Speakers and the End of Islam*, (London: Routledge, 2002), xv-xvii.

13 Kapitaikin, “The Daughter of al-Andalus’: Interrelations between Norman Sicily and the Muslim West,” 113–134.

14 Kapitaikin, “The Daughter of al-Andalus’: Interrelations between Norman Sicily and the Muslim West,” 113–134.

Rise of Roger II

Jean Castex summarizes the complex and lengthy Norman conquest of Muslim Sicily: “the Hautevilles had begun their conquest of Sicily in 1061. In 1072, they made a triumphal entrance into Palermo, which had been the Muslim capital city since 831.”¹⁵ Roger I, father of Roger II (who would become patron of the Cappella), conquered the island. The Normans, in actuality, were not inheriting a previously abandoned throne, but rather weaving a myth of the resurgence of a king of Sicily who had never existed.¹⁶ As an apostolic legate, Roger II used his religious authority to drive his succession to a mythical Sicilian crown.¹⁷ In order to strengthen his unsure position, Roger II sponsored royally themed art and architecture, like the Cappella Palatina, that included his population’s cultural diversity to further his image as a legitimate king.

Though known to us as a Norman king, Roger II was merely descended from Normandy, set to succeed the throne in Sicily. He was born in 1095 and reared in the area that he would rule, in Messina, Sicily, either having spent little or no time in Normandy itself.¹⁸ He was exposed to its diversity whilst growing up. The influences around Roger II in his childhood include a “Greek-Byzantine environment” with his mother, regent Adelaide del Vasto, and a Norman father, Roger I.¹⁹ He was exposed more deeply to Islam upon his arrival to Palermo, the former capital of Muslim Sicily, composed mainly of Muslims, where he assumed a knighthood in 1112.²⁰ Roger II was crowned king of Sicily, his fabricated position, in 1130, and thus began his reign over his diverse kingdom.²¹

While learning under a variety of diverse cultural influences, Roger II was nurtured to rule his kingdom with exposure to the groups present in Sicily, which resulted in benevolent toleration later on. His toleration of religious and ethnic diversity was not due to weakness as a king or ruler, as Roger II himself is noted for enterprise in ensuring success for his kingdom, and for

15 Castex, *Architecture of Italy*, (Westport: ABC-CLIO, LLC, 2008), 93.

16 Karen C. Britt, “Roger II of Sicily: Rex, Basileus, and Khalif? Identity, Politics, and Propaganda in the Cappella Palatina,” *Mediterranean Studies* 16 (2007): 26, <http://www.jstor.org/stable/41167003>.

17 Lisa Reilly, “Roger II & Medieval Visual Culture,” (unpublished manuscript. September 2019), 3–4, typescript.

18 “Roger II,” *Britannica Academic*, s.v., accessed September 5, 2019, <https://academic.oxfordjournals.org/levels/collegiate/article/Roger-II/83727>.

19 Britt, “Roger II of Sicily: Rex, Basileus, and Khalif? Identity, Politics, and Propaganda in the Cappella Palatina,” 24.

20 “Roger II,” *Britannica Academic*.

21 Kauffmann, “Hauteville, House of family.”

possessing ambition rather than fragility.²² Under his lead, Sicily became a powerful contender in the Mediterranean political and economic realm.²³

In 1132, the Norman court began to issue official documents in the Arabic language, taking precedence over the usage of Greek or Latin.²⁴ Scholar of Norman Sicily Jeremy Johns describes the Norman court as a diwan, the word for an Islamic court, because of its genuine Islamic structure. Johns identifies the Arabic decrees of 1132 as the earliest products of the Norman diwan, deeming it a turning point for Roger II's government.²⁵ According to Johns, the formation of a court based on Islamic models is, to some extent, rooted in the Norman conquest and the agreements and interactions with the Muslim government that the Normans had conquered. But, the Norman court did not draw from the history of Muslim Sicily alone, but more prominently from contemporary Islamic administrations. Most notably, the Norman Sicilian court structure mirrors the contemporary government of Fatimid Egypt.²⁶ In modeling itself after the Fatimid government and connecting with North Africa through trade, Sicily also adopted aspects of its visual culture, visible through the extensive Fatimid influence on Norman inscriptions in Kufic script on the art and architecture in Sicily.²⁷ The connections between the Normans in Sicily and Fatimid Egyptians is also evident through the presence of Fatimid carpenters and painters who worked on the muqarnas ceiling of the Cappella Palatina.²⁸

King Roger II's sponsorship of art and architecture, illustrating a complex interplay between cultural elements from distant areas, was not a mistake or coincidence. In conjunction with the creation of an Islamic style

22 "Roger II," *Britannica Academic*.s.v.

23 Luigi Berto, et al. "Roger II, king of Sicily," *The Oxford Dictionary of the Middle Ages*, Oxford University Press, 2010, <https://www.oxfordreference.com/view/10.1093/acref/9780198662624.001.0001/acref-9780198662624-e-5052>.

24 Johns, *Arabic Administration in Norman Sicily: The Royal Diwan*, 91.

25 Johns, *Arabic Administration in Norman Sicily: The Royal Diwan*, 91.

26 Johns, *Arabic Administration in Norman Sicily: The Royal Diwan*, 12.

27 Jeremy Johns, et al, "The Arabic Inscriptions of the Norman Kings of Sicily. A Reinterpretation," *The Royal Workshops in Palermo during the Reigns of the Norman and Hohenstaufen Kings of Sicily in the 12th and 13th century*, 2006, 324, https://www.academia.edu/4702469/_The_Arabic_inscriptions_of_the_Norman_kings_of_Sicily_a_reinterpretation_.

28 Jeremy Johns, et al. "A Tale of Two Ceilings. The Cappella Palatina in Palermo and the Mouchroutas in Constantinople," *Art, Trade, and Culture in the Near East and India: From the Fatimids to the Mughals*, (London: Gingko Library Art Series, 2016), 2, https://www.academia.edu/22749655/A_Tale_of_Two_Ceilings._The_Cappella_Palatina_in_Palermo_and_the_Mouchroutas_in_Constantinople_revised_pre-print_version_now_published_.

court, Roger used interactions with the Fatimid administration to deliberately cast his position as the mediator of mixed society into the buildings he patronized, reflecting the translation of his people into a multidimensional, artistic representation.²⁹

The Cappella Palatina & Ceiling

The Cappella Palatina, in Palermo, Sicily, perpetuates a visual narrative of Roger's connections across the Mediterranean with both Muslim and Christian areas, and his consolidation of power through inclusivity. Built during Roger's rule in the mid-1100s, the Cappella lies within the Norman palace in the capital.³⁰ Visually striking, with gilded Byzantine mosaics depicting various Christian images, geometric patterns, and Kufic inscriptions, this chapel embodies the distinct and multifaceted vocabulary of which Norman Sicilian art is composed.³¹ (Fig. 3) Combining Byzantine, Norman, and Islamic elements, the ceiling in particular conveys how what we may consider as separate stylistic components in fact synchronize to create the unique style generated by Roger II's patronage and tolerant rule.



Figure 3.

Schaffer, Andrea. *Cappella Palatina*. January 2, 2018. <https://www.flickr.com/photos/aschaf/27774519079>.

²⁹ Johns, "A Tale of Two Ceilings. The Cappella Palatina in Palermo and the Mouchroutas in Constantinople," 3.

³⁰ Castex, *Architecture of Italy*, (Westport: ABC-CLIO, LLC, 2008), 93.

³¹ Johns, "The Arabic Inscriptions of the Norman Kings of Sicily. A Reinterpretation," 324.

Most evidently, the Cappella Palatina ceiling is comprised of muqarnas, seemingly carved niches that create three-dimensional geometric patterns accompanied by decoration on the surfaces.³² (Fig. 4) Though one may misinterpret the figural representations on the ceiling as stemming from Byzantine or Norman sources alone, the humans present in the ceiling paintings do not remove the possibility of Islamic influence. The depictions of people interacting in court scenarios are distinctly reminiscent of Fatimid style and court life due to their dress.³³ In addition, the intricate painting includes organic, geometric, figural, and written components, which could be traced partially, but not completely, to Islamic inspiration. The star-shaped muqarnas with their symmetry, repetition, and geometry echo Islamic styles of non-figural art used in mosques and other buildings. The floral motif at the center draws from the use of vegetal forms in lieu of figures, used in decoration of mosques as well. (Fig. 5) The Kufic script in particular, which trails along the shape of the star, is derived from Fatimid Egypt.



Figure 4.

Luiz Bernardes Ribeiro, José. *Creation and ceiling—Capela Palatina-Palermo. January 27, 2015.* https://commons.wikimedia.org/wiki/File:Creation_and_ceiling_-_Capela_Palatina_-_Palermo_-_Italy_2015.JPG.

32 Lara Tohme, et al. “muqarnas,” *The Oxford Dictionary of the Middle Ages*, Oxford University Press, 2010, accessed September 5 2019, <https://www.oxfordreference.com/view/10.1093/acref/9780198662624.001.0001/acref-9780198662624-e-4119>.

33 Margaret Graves, “Ceilings in Islamic architecture,” *Grove Art Online*, July 2, 2009, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T2082118>.



Figure 5.

Skramstad, Per-Erik. The Palatine Chapel in Palermo. The Wonders of Sicily. <http://www.wondersofsicily.com/palermo-palatine-chapel.htm>

The figural elements and the “casual interest in naturalism” represent non-religious Fatimid Egyptian styles of decoration.³⁴ The loosely realistic depictions of the figures in the ceiling would have been unacceptable in religious buildings in Egypt at the time, but their presence in the paintings connects deeply with the written and geometric elements, due to the underlying Islamic court themes in the scenes. (Fig. 6) A significant image that draws from outside of Sicily is the camel caravan on the ceiling, which could draw from either North Africa or the Middle East. (Fig. 7) The comparable architectural decoration in North

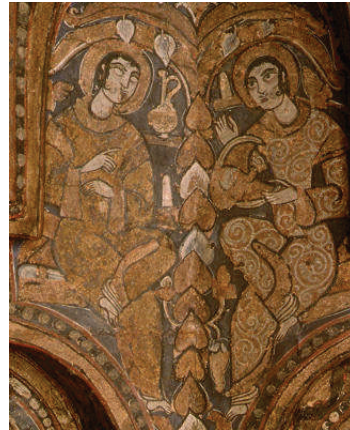


Figure 6.

Rock, Joe. Two Seated Figures in the Painted Wooden Ceiling of the Palatine Chapel. http://warfare.net.au.net/12/Cappella_Palatina-ceiling-2_seated.htm.

³⁴ Jonathan M. Bloom, “Fatimid,” Grove Art Online, 2003, last modified May 26, 2010, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T027650>.



Figure 7.

Rock, Joe. Caravan in the Painted Wooden Ceiling of the Palatine Chapel.

http://warfare.net.au.net/12/Cappella_Palatina-ceiling-Caravan.htm.

Africa, from which the Cappella ceiling is derived, no longer exists today.³⁵ Hence, the ceiling is now considered to be one of the best surviving examples of North African muqarnas ceilings.³⁶ Due to their centrality in the Mediterranean, the Normans did not solely imitate or draw influence from the court of Fatimid Egypt. The island's geographic orientation predicted the inevitability that Sicily would soak up the traditions of cultures from all over.³⁷ There still remains a sense of uncertainty in attributing all elements and motifs of the ceiling. The style of painting on the muqarnas ceiling connects, in addition, with Hellenistic paintings found in Egypt.³⁸

Ernst J. Grube, J. M. Rogers, and Jeremy Johns, as well as other scholars of the Cappella Palatina, note the high possibility that the artists and workers

35 Giuseppe Bellafore, "Sicily" in "Islamic art," Grove Art Online, 2003, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T041771>.

36 J. M. Rogers, "c. 900-c. 1900" in "Islamic art," Grove Art Online, 2003, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T041771>.

37 Dalu Jones, "The Cappella Palatina in Palermo: Problems of Attribution," *AARP; Art and archaeology research papers* 2, (1972): 47.

38 Ernst J. Grube, et al., "Egypt" in "Islamic art," Grove Art Online, 2003, accessed September 5, 2019, <https://doi.org/10.1093/gao/9781884446054.article.T041771>.

who were hired to create the Cappella Palatina were in part Muslims, or even more specifically, Muslims from Fatimid Egypt. This notion reiterates that the incorporation of Islamic themes in the ceiling was not imitation by Norman artists, but rather artisans from North Africa directly exerting their style and experience of the royal court into the production of the painting. Lev Kapitaikin also draws attention to the possible effects of Western Islamic spheres of influence, with the muqarnas and arches imitating similar features from mosques in Morocco.³⁹

Motifs on the ceiling can also be traced to European Muslim areas, not only from North Africa and the Eastern Mediterranean. The figures leading the court are distinctively Fatimid in their dress and in the style of painting.⁴⁰ On the other hand, the royal eagle appears frequently on Spanish Muslim textiles, playing into the culture of interchange taking place in Norman Sicily at the time.⁴¹ (Fig. 8) The influence of portable objects, such as textiles, on Norman Sicilian visual culture, will be further explored in this case study.

Though scholars tend to pinpoint locations from which differing images on the Cappella ceiling spread, Eva Hoffman acknowledges that some motifs, animal images in particular, draw from more universal representations of royalty.⁴² Other art sponsored by Roger II also emulates this establishment of



Figure 8.

Eagle on the ceiling of the Cappella Palatina (1140-'63). <http://www.hubert-herald.nl/ItalSicily.htm>.

39 Kapitaikin, "The Daughter of al-Andalus': Interrelations between Norman Sicily and the Muslim West," 113–134.

40 Rogers, "c. 900-c. 1900" in "Islamic art."

41 Kapitaikin, "The Daughter of al-Andalus': Interrelations between Norman Sicily and the Muslim West," 113–134.

42 Eva R. Hoffman, "Pathways of Portability: Islamic and Christian Interchange from the Tenth to the Twelfth Century," *Late Antique and Medieval Art of the Mediterranean World*, (Hoboken: Wiley, 2007), 330–331.

royal power through visual means, with scenes imitating a ruler's relation to his/her people or other governments, like the prevailing of a predatory animal over its prey. On the mantle of Roger II, an intricately woven ceremonial cape, a lion slaughters a camel for food, possibly alluding to the Norman succession of Muslim rule in Sicily. (Fig 9) People from all over the Mediterranean area, including from different kingdoms and religions, would be able to easily recognize the meaning of these royal images, reinforcing their universality. A painted portion of the Cappella ceiling echoes the themes and visuals of the Mantle of Roger II, with a symmetrical depiction of a red throne with a palm tree decoration, and a lion as the head of the throne. (Fig. 10) Another universal artistic theme employed by monarchies is the depiction of the court. This representation of the lavishness with which monarchs lead their comfortable lives extends beyond the many cultures of the Mediterranean into all parts of the world, where the same visual expressions of the royal power complex recur.⁴³ The ceiling displays many court-themed images of figures, with some more directly related to the king, like this painting of the crowned and robed king flanked by court attendees fanning him. (Fig. 11)

In considering the ceiling of the Cappella Palatina and its various Islamic influences and motifs, it is important to re-contextualize this muqarnas ceiling, so as not to isolate it as a decorative element that is out of place. Other



Figure 9.

Weltliche Schatzkammer Wienc. November 15, 2007. https://commons.wikimedia.org/wiki/File:Weltliche_Schatzkammer_Wienc.jpg.

43 Jones, "The Cappella Palatina in Palermo: Problems of Attribution," 59–60.



Figure 10.

Ducal Throne on the ceiling of the Cappella Palatina. <http://www.hubert-herald.nl/ItalSicily.htm>



Figure 11.

Rock, Joe. King in the Painted Wooden Ceiling of the Palatina Chapel. http://warfare.net.au.net/12/Cappella_Palatina-ceiling-King.htm.

parts of the ceiling, separate from the long, main portion of the muqarnas section, very clearly depict Christian images. Offset from the ceiling over the main hall, this section maintains the repetitive vegetal patterns to frame the figural paintings, but in this case, the figures are notably Christian, with halos encircling their heads and multiple crosses. (Fig. 12 & 13) They are still painted amongst animal themes, but these animals are more likely tied to Biblical stories and representations. The Christian figural paintings also lie within carved, oblong niches, tying back to the muqarnas in the main portion of the ceiling.

The Cappella Palatina palpably displays layers of years of cultural overlap occurring in diverse Sicily, and it can also adopt another sub-classification: Romanesque, emerging from the notion proposed earlier in scholarship by Dalu Jones.⁴⁴ With all of its complex decorations, the Cappella Palatina follows the model of a Romanesque church in terms of its plan, but the decoration of the chapel's walls are still largely Byzantine. (Fig. 14) It should be noted that this is ultimately a Christian church made for royal access in a palace inhabited by Norman Christian kings. Specifically sponsored and created for a ruler with a direct connection to the church, this central purpose of the Cappella Palatina dictates the presence of the most noticeable mosaics and figural scenes as Christian, just as the figural ceiling paintings could be Christian as well.⁴⁵



Figure 12.

Skramstad, Per-Erik. *The Palatine Chapel in Palermo, detail of the ceiling. The Wonders of Sicily.* <http://www.wondersofsicily.com/palermo-palatine-chapel.htm>.

44 Oleg Grabar, review of *The Painted Ceilings of the Cappella Palatina*, by Ernst J. Grube, *The Art Bulletin* 90, no. 1 (March 2008): 132, <http://www.jstor.org/stable/20619593>.

45 Jones, "The Cappella Palatina in Palermo: Problems of Attribution," 46.



Figure 13.

Skramstad, Per-Erik. *The Palatine Chapel in Palermo, the magnificent wooden ceiling. The Wonders of Sicily.* <http://www.wondersofsicily.com/palermo-palatine-chapel.htm>.

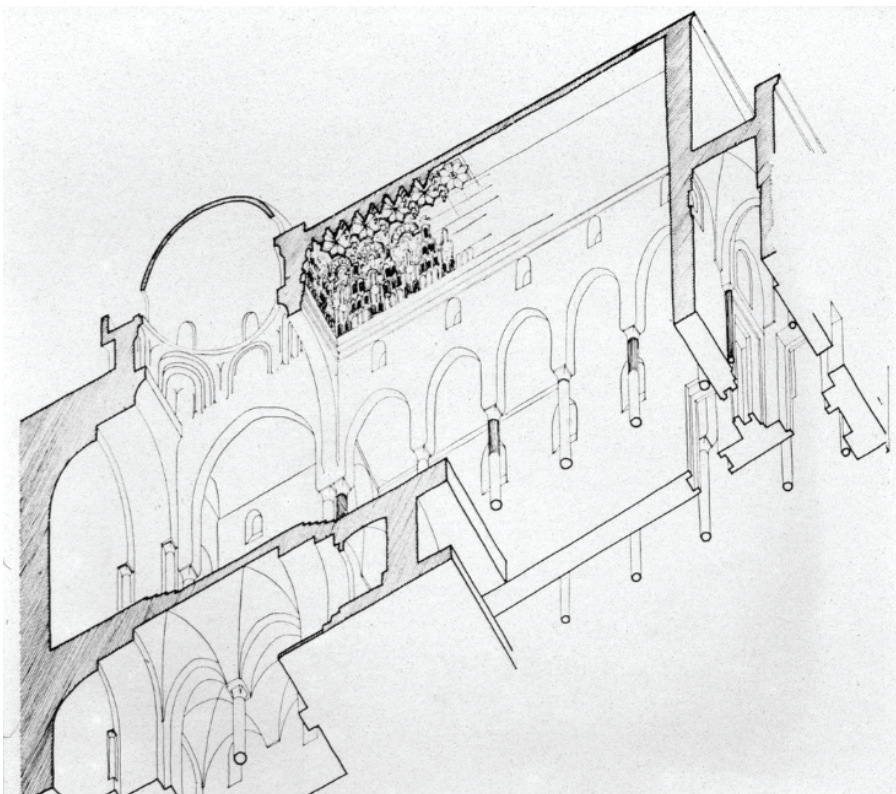


Figure 14.

Unknown. *Begun 1130. Cappella Palatina. Axonometric section. Palermo. Architecture.* https://library.artstor.org/asset/ABRMAWR_SITE_10312104656.

Conclusion

The ceiling of the Cappella Palatina, when looking beyond its initial visual impression, is a composition of various cultural styles, media, motifs, and symbols, all adapted to a masterful, harmonious interplay, despite the seemingly distinct techniques and backgrounds. While many scholars identify and analyze singular components of both the ceiling and other decorations in the Cappella, there is a sense of ambiguity in singling out the source of certain images, figures, patterns, and more. Different images, such as lions, camels, and court scenes, appear in art from cultures on separate sides of the Mediterranean, and with Sicily's trade connections, different artistic styles have coalesced on one ceiling. The muqarnas ceiling and its extensive figural and non-figural paintings can connect easily to Fatimid Egypt, but in reality, it draws from other influences as well. The ceiling is not necessarily an 'Islamic ceiling' in a Christian building, but rather a ceiling that was inspired by Islamic traditions, and woven with motifs and meanings from art across the Mediterranean. This ambiguity can be perceived as a challenge or block in thorough and accurate research of the Cappella Palatina, but it uncovers a broader sense that the artistry of Norman Sicily, especially under Roger II, is a singular and distinct Mediterranean cultural expression. Roger II cunningly tailored his art and architecture of his new kingdom to fit both the diverse community that he was ruling, and the rapid interconnectedness of this section of the world. The king's political prowess drove this concept of representation and maintained diversity in Norman Sicily to secure support for his rule and validate his kingship. The lavish and complex art in the Cappella Palatina is an attempt to project an image of royal authority to both other rulers and to Roger's own people. Modern scholars can salute Roger II for making Norman Sicily incredibly appealing to a world in which variety of cultural traditions and coexistence has become paramount. The Cappella Palatina's ceiling can be identified as stereotypically Islamic at first look, but upon close examination, the decoration unites visual vocabularies from many cultures. Though Sicily and its art in medieval times may have been catalyzed by diversity, it was the unity of the people of the area encouraged by Roger that led the way for a unique visual language to shine through.

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An Investigation in Tournaments with Bidirectional Arcs

Cheng Qian

Author Background: Cheng Qian grew up in China and attended Tsinghua University High School. His Pioneer research concentration was in the field of Mathematics and titled "Introduction to Combinatorics and Graph Theory."

Abstract

This research mainly explores a particular type of tournament with bidirectional arcs. For the first two sections, the paper focuses on the basic previously-proved conclusions related to directed graphs and tournaments, including discussions about Euler graph and various kinds of Hamiltonian problems about paths and cycles.

The main section includes the majority of the new result. It shows the definition and properties of a bidirectional tournament in detail and focuses on the special transformation process as well as theorems related to Hamiltonian problems and strongly connected component (SCC). The maximum number of strongly connected induced subgraphs of order m of a bidirectional tournament with n bidirectional arcs is also computed.

Key Words: Directed Graph, Bidirectional Tournament, Hamiltonian Problems, Strongly Connected Component.

1. Directed Graph

1.1 Introduction

The concept of directed graphs (or digraphs) is one of the richest theories in graph theory, mainly because of its applications to real-world problems. For example, flow networks with valves in the pipes and electrical networks are represented by directed graphs. They are applied in abstract representations of computer programs and are an invaluable tool in the study of sequential machines.^[1] There are also theories about directed graphs that originate from our daily life

and exploration due to our curiosity. For example, the Euler digraph actually came from Euler's confusion about traveling around the world. This section will mainly explore the basic properties and theorems related to directed graphs.

1.2 Definition and Properties

A directed graph D is a pair (V, A) , where V (the vertex set) is a nonempty set whose elements are called the *vertices* and A (the arc set) is the set of ordered pairs of distinct elements of V . The elements of A are called the *arcs* of D . Basically, it refers to a set of objects (vertices or nodes) that are connected, where all the arcs are directed from one vertex to another.

Therefore, for each arc a in the set A , since it is directed, it can be written in the form of (u, v) , where a connected vertices u and v and directs from u to v . In addition, in a directed graph, we can split the notion of degree to *indegree* (denoted d^-) and *outdegree* (denoted d^+), indicating whether the arc is pointing to or from the vertex.^[2] The total degree of a vertex is $d(v) = d^-(v) + d^+(v)$. From this definition, we may easily derive the following proved theorem.

Theorem 1.1: In the directed graph $D = (V, A)$ where $V = \{v_1, v_2, \dots, v_n\}$,

$$\sum_{i=1}^n d^-(v_i) = \sum_{i=1}^n d^+(v_i) = |A|.$$

The proof is simple enough since every arc contributes to exactly one indegree and one outdegree. This equation shows one of the directed graph's basic properties.

The definitions for (directed) *walks*, *paths*, and *cycles* in a directed graph are similar to those for undirected graphs, except that the direction of the arcs needs to be consistent with the order in which the walk is traversed.

A (directed) walk in a digraph $D = (V, A)$ is a sequence $v_0 a_1 v_1 a_2 \dots a_k v_k$, where $v_i \in V$ and $a_i \in A$ are such that $a_i = v_{i-1} v_i$ for $1 \leq i \leq k$, no arc is being repeated. As there is only one arc of the form $v_i v_j$, the walk can also be represented by the vertex sequence $v_0 v_1 \dots v_k$. A vertex may appear more than once in a walk. Clearly, the length of the walk is k . If $v_0 \neq v_k$, the walk is open, and if $v_0 = v_k$, the walk is closed. A walk is *spanning* if $V = \{v_0, \dots, v_n\}$. A (directed) path is an open walk in which no vertex is repeated. A (directed) cycle is a closed walk in which no vertex is repeated. A digraph is acyclic if it has no cycles.

A *semi-walk* is a sequence $v_0 a_1 v_1 a_2 \dots a_k v_k$ with $v_i \in V$ and $a_i \in A$ such that either $a_i = (v_{i-1}, v_i)$ or $a_i = (v_i, v_{i-1})$ and no arc is repeated. The length of the semi-walk is k . If $v_0 \neq v_k$, the semi-walk is open, and if $v_0 = v_k$, the semi-walk is closed. If no vertex is repeated in an open (closed) semi-walk, it is called a semi-path (semi-cycle). A spanning path of a digraph is called a Hamiltonian path and a spanning cycle is called a *Hamiltonian cycle*. A digraph with a Hamiltonian cycle is said to be *Hamiltonian*.^[1]

1.3 Strong Connectivity and Weak Connectivity

1.3.1 Definition

A digraph is said to be *strongly connected* or *strong*, if every two of its distinct vertices u and v are such that u is reachable from v and v is reachable from u . A digraph is *unilaterally connected* or *unilateral*, if either u is reachable from v or v is reachable from u and is *weakly connected* or *weak*, if u and v are joined by a semi-path.

1.3.2 Properties Related to Connectivity^[1]

The following proved Theorem shows us how to determine a strongly connected digraph.

Theorem 1.2: If we define the *arc sequence* to be an alternating sequence of vertices and arcs connected, then a directed graph is strongly connected if and only if it contains a spanning closed arc sequence.

Proof: *Necessity:* Let $D = (V, A)$ be a strong digraph with $V = \{v_1, v_2, \dots, v_n\}$. Then there is an arc sequence from each vertex in V to every other vertex in V . Therefore, there exists in the D arc sequence Q_1, Q_2, \dots, Q_{n-1} such that the first vertex of Q_i is v_i and the last vertex of Q_i is v_{i+1} , for $i = 1, 2, \dots, n-1$. Also, there exists an arc sequence, say Q_n , with first vertex v_n and the last vertex v_1 . Then the arc sequence obtained by traversing the arc sequences Q_1, Q_2, \dots, Q_n in succession is a closed arc sequence of D .

Sufficiency: Let u and v be two distinct vertices of V . If v follows u in any closed arc sequence, say Q of D , then there exists a sequence of the arcs of Q forming an arc sequence from u to v . If u follows v in Q , then there is an arc sequence from u to the last vertex of Q and an arc sequence from that vertex to v . An arc sequence from u to v is then obtained by traversing these two arc sequences in succession.

Besides the connectivity for the whole graph, there is also something more about connectivity in its components. A strongly connected component refers to the strongly connected sub-digraph of the original directed graph. We have already proven above the relationship between the strongly connected digraph and closed arc sequence, but there also exist digraphs that do not contain cycles. If an undirected graph does not have any cycles, then it is a tree or a forest. If a directed graph contains no cycle, we define it as *directed acyclic graph* (DAG).^[2] The proved Theorem below shows one important property of DAG.

Theorem 1.3: Every directed graph is a DAG of its strongly connected components.

Proof: We shrink each of the strongly connected components down to a single node. In addition, if there is an arc from some vertices in the first to some vertices in the second, we draw an arc between two of them correspondingly. In this case, the resulting directed graph has to be a DAG. If there is a cycle containing two or more strongly connected components, then those components can merge into a larger, single, strongly connected component. Therefore, the graph can finally be shown in the form of a DAG of its strongly connected components.

1.4 Euler Digraphs

1.4.1 Definition

A *Euler digraph* is a connected digraph where every vertex has an indegree equal to its outdegree. The name, of course, comes from the directed version of Euler's Theorem. Recall that a Euler tour in a digraph is a directed closed walk that uses each arc exactly once. Then in this terminology, by the famous theorem of Euler, a digraph admits a Euler tour if and only if it is a Euler digraph.

However, beyond this point of historical interest, Euler digraphs are also interesting since they form a class of intermediate complexity between undirected graphs and fully general digraphs for many problems.

In addition, a *Eulerian path* is a path in graph that visits every arc exactly once. A *Eulerian circuit* is a Eulerian path which starts and ends on the same vertex. These terms will appear in the proofs that follow.

1.4.2 Properties Related to Euler Digraph^[3] and Euler Tour

The following proved theorem^[1] shows us how to determine an Euler digraph.

Theorem 1.4: A digraph $D = (V, A)$ admits a Euler tour if and only if D is connected and for each of its vertices v , $d^-(v) = d^+(v)$.

Proof: *Necessity:* Let D be a Euler digraph. Therefore, it contains a Eulerian walk, say W . In traversing W , every time a vertex v is encountered we pass along an arc incident towards v and then an arc incident away from v . This is true for all the vertices of W , including the initial vertex of W , say v , because we began W by traversing an arc incident away from v and ended W by traversing an arc incident towards v .

Sufficiency: Let for every vertex v in D , $d^-(v) = d^+(v)$. For any arbitrary vertex v in D , we identify a walk, starting at v and traversing the arcs of D at most once each. This traversing is continued until it is impossible to traverse further. Since every vertex has the same number of arcs incident towards it as away from it, we can leave any vertex that we enter along the walk and the traversal then stops at v . Let the walk traversed so far be denoted by W . If W includes all arcs of A , then the result follows. If not, we remove from D all the arcs of W and consider the remainder of A . By assumption, each vertex in the remaining digraph, say D_1 , is such that the number of arcs directed towards it equals the number of arcs directed away from it. Further, W and D_1 have a vertex, say u , in common, since D is connected. Starting at u , we repeat the process of tracing a walk in D_1 . If this walk does not contain all the arcs of D_1 , the process is repeated until a closed walk that traverses each of the arcs of D exactly once is obtained. Therefore, D is a Euler digraph.

We can learn from the above about the existence of the Euler Digraph and the property it must fulfill. However, for a Euler Digraph, there may exist more than one way of completing the Euler Tour, and for that, the *BEST* Theorem gives a product formula for the number of Eulerian circuits in directed graphs. The name is an acronym of the names of people who discovered it: de Bruijn, van Aardenne-Ehrenfest, Smith, and Tutte.

Here we have to first define some terms for later use. The out-branching of a vertex v means the number of spanning trees in the directed graph in which every vertex has a directed path to v . On the other hand, in-branching of a vertex v means the number of spanning trees in the directed graph in which every vertex has a directed path from v . A balanced graph is that for every vertex v in the digraph, $d^-(v) = d^+(v)$. Now we can together appreciate the *BEST* Theorem^[4].

Theorem 1.5 (de Bruijn, van Aardenne-Ehrenfest, Smith, and Tutte):

Let $D = (V, A)$ be an Euler digraph, and $w \in V$ an arbitrary vertex. The number of Euler tours in D is

$$t_D(w) \prod_{v \in V} (d^+(v) - 1)!$$

where $t_D(w)$ is the number of out-branchings of D rooted in w .

Proof: Let $ww' \in A$, and let T be an Euler tour of D . Observe that T induces a permutation π_v of the out-arcs of v for every $v \in V$, according to the order in which these arcs are visited in T , starting the count from ww' . Also, note that T can be recovered from this collection of permutations, and conversely, every such collection of permutations $\{\pi_v\}_{v \in V}$ defines a closed trail in D containing the arc ww' , although not every collection of permutations induces an Euler tour. For a collection of permutations $P = \{\pi_v\}_{v \in V}$, let $F(P) = \{\pi_v(d^+(v)) \mid v \in V, v \neq w\}$ be the set containing the last outgoing arc from every vertex except w . We claim that P defines an Euler tour if and only if $F(P)$ is an in-branching in D rooted in w .

On the one hand, let P be defined via an Euler tour T . The set $F(P)$ forms a digraph where every vertex except w has out-degree 1; hence $F(P)$ forms an in-branching rooted in w if and only if it is acyclic. We claim that for every arc $uv \in F(P)$, $v \neq w$, the last out-arc of u is visited before the last out-arc of v in T , if we begin the counting from ww' . Indeed, uv is the last out-arc of u visited in T by definition, and clearly whatever arc follows uv in T is an out-arc of v visited after uv . Since the out-degree of w in $F(P)$ is zero, it follows that $F(P)$ is acyclic, and that $F(P)$ is an in-branching rooted in w .

On the other hand, let P be a collection of permutations such that $F(P)$ forms an in-branching, and let T be the closed tour defined by P starting from the arc ww' . Then $D - T$ is a balanced digraph. Let H be a connected component of $D - T$. Clearly, for every vertex v that is not of degree zero in $D - T$, the out-arc of v in $F(P)$ is contained in $D - T$. But then the set F_H of out-arcs of $F(P)$ of vertices in H forms a subgraph of H where every vertex has out-degree 1, which necessarily contains a cycle. This contradicts our assumption on P .

The formula follows from this claim. For every in-branching B of D rooted in w , there are exactly

$$t_D(w) \prod_{v \in V} (d^+(v) - 1)!$$

collections P of permutations such that $F(P) = B$: for every vertex $v \neq w$, the in-branching B fixes the last out-arc of v in P , whereas for w , the out-arc ww' is the first out-arc of w by definition. Any choice of a permutation π_v on the remaining arcs does not affect $F(P)$.

2. Tournament

2.1 Definition

A *tournament* is a directed graph obtained by assigning a direction for each edge in an undirected complete graph. That is, it is an orientation of a complete graph, or equivalently a directed graph in which every pair of distinct vertices is connected by a directed arc with any one of the two possible orientations.^[2]

But why is this graph called a tournament? This is because the graph can be illustrated in a different way—each vertex represents a player and each edge indicates an outcome of the game between the players connected. In particular, an arc from u to v indicates that player u defeated player v . In a round-robin tournament, every pair of players has a match. Thus, in a tournament there is either an arc from u to v or an arc from v to u (but not both) for every pair of distinct vertices u and v .

2.2 Basic Properties of Tournaments

2.2.1 Extension of Previous Theorem

A tournament is a special kind of directed graph, so the basic theorem of directed graph proved before, Theorem 1.1, is also satisfied for tournaments. Now, we can use this to prove the following new theorem.

Theorem 2.1: Let $T = (V, A)$ be a tournament of degree n . Then for T , it always satisfies:

$$\sum_{i=1}^n (d^+(v_i))^2 = \sum_{i=1}^n (d^-(v_i))^2$$

Proof: This is easy to prove by rearranging the equation we want to prove. For each vertex in a tournament, the sum of its indegree and outdegree should equal $n - 1$.

$$\begin{aligned} \text{Theorem 2.1} &\Leftrightarrow \sum_{i=1}^n (d^+(v_i))^2 - \sum_{i=1}^n (d^-(v_i))^2 = 0, \\ &\Leftrightarrow \sum_{i=1}^n (d^+(v_i))^2 - (d^-(v_i))^2 = 0. \end{aligned}$$

After factorization we can obtain the following transformation

$$\Leftrightarrow \sum_{i=1}^n (d^+(v_i) + d^-(v_i))(d^+(v_i) - d^-(v_i)) = 0.$$

For each vertex in a tournament, the sum of its indegree and outdegree should equal $n - 1$, so $d^+(v_i) + d^-(v_i) = n - 1$. Therefore,

$$\begin{aligned} &\Leftrightarrow (n-1) \sum_{i=1}^n (d^+(v_i) - d^-(v_i)) = 0, \\ &\Leftrightarrow (n-1) \left(\sum_{i=1}^n d^+(v_i) - \sum_{i=1}^n d^-(v_i) \right) = 0. \end{aligned}$$

From Theorem 1.1 we have already known $\sum_{i=1}^n d^+(v_i) - \sum_{i=1}^n d^-(v_i) = 0$, so the theorem can thus be proved successfully.

2.2.2 King Chicken

Chickens are rather aggressive animals and we will use them to illustrate some definitions and interesting theories related to tournaments. Chickens usually show dominance by pecking others, and we say that a chicken virtually pecks others if chicken u directly pecks chicken v , or chicken u pecks some other chicken w who in turn pecks chicken v . For each pair of chickens, there is only one pecking, either from u to v or from v to u . A chicken that *virtually pecks* all the other chickens is called a *King Chicken*^[2], and the theorem follows.

Theorem 2.2 (King Chicken Theorem, Mauer): In an n -chicken tournament, the chicken with the largest outdegree is a King Chicken.

In mathematical language, it can be paraphrased as the following.

In a tournament T of order n , there always exists a vertex that can reach all the other vertices through paths whose length are all at most 2.

Proof: Suppose the vertex with the largest outdegree is v_1 , and for every arc starting at point v_1 , suppose their endpoints form a set $N^+(v_1)$. If the theorem does not hold, then there must exist a vertex v_2 that cannot be reached from v_1 through a path of length at most 2. Of course, v_2 cannot belong to set $N^+(v_1)$, so for the arc connecting these two vertices, it directs from v_2 to v_1 . Moreover, for each vertex $v_i \in N^+(v_1)$, consider the arc connecting v_1 and v_2 . If it directs from v_1 to v_2 , then v_2 can be reached from v_1 by path, say $P = v_1v_i v_2$. Therefore, for every vertex in $N^+(v_1)$, they should all receive an indegree from v_2 . Conversely, considering v_2 , v_1 and every vertex in $N^+(v_1)$ all contribute to v_2 's outdegree. Therefore, $d^+(v_2) \geq |N^+(v_1)| + 1 = d^+(v_1) + 1$, which contradicts the supposition that v_1 is the vertex with the largest outdegree. Therefore, the theorem is successfully proved by contradiction.

Actually, in a tournament there can be more than 1 King Chicken. The following Figure 1 gives a condition where all the chickens are King Chickens.

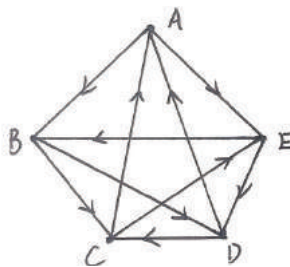


Figure 1.
All chickens are King Chicken

The following theorem shows us this possibility exists in every directed graph of order n —everyone is a king!^[5]

Theorem 2.3 (Mauer): There always exists a tournament of order $n(n \geq 4)$, where every chicken is a King.

Proof: For $n = 5$ and $n = 6$, the condition is satisfied. For $n = 5$, the graph above has already provided an example that satisfies. The following Figure 2 can prove the existence.

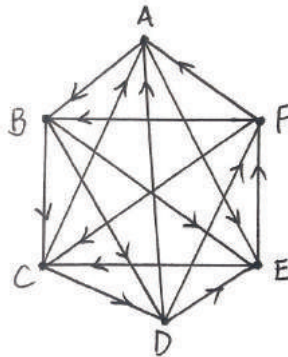


Figure 2.
Construction when $n = 6$

Now we apply the induction to prove the existence of an everyone-a-king graph for all $n \geq 4$.

Suppose a tournament of order n satisfies the condition, then for tournament of order $n + 2$, we first compose a graph T of order n that satisfies the condition in it, where T includes vertices v_1, v_2, \dots, v_n . For the 2 new vertices added, v_{n+1} and v_{n+2} , let all the new arcs created linking v_i ($i \in 1, 2, \dots, n$) and v_{n+1} direct to v_{n+1} , and let all the new arcs created linking v_i ($i \in 1, 2, \dots, n$) and v_{n+2} direct from v_{n+2} . Then let the arc linking v_{n+1} and v_{n+2} directs to v_{n+2} .

For vertices in T , they can reach v_{n+1} directly and reach v_{n+2} by passing through v_{n+1} . For v_{n+1} , it can reach v_{n+2} directly and reach vertices in T by first passing through v_{n+2} . For v_{n+2} , it can reach vertices in T directly and reach v_{n+1} by first passing through any one vertex in T , from where directly getting to v_{n+1} . Therefore, the tournament of order $n + 2$ is also an everyone-a-king graph that satisfies the condition. Thus, the theorem is proved successfully by induction.

After the theorem about when everyone can be a king, now let us consider when there can only will be one King Chicken (usually to be a king,

one has to be unique, of course). With the King Chicken Theorem laying the foundation, the following theorem can thus be proved.^[5]

Theorem 2.4 (Mauer): If there is only one true King Chicken in the n -chicken tournament, then it has to directly peck all the other $n-1$ chickens.

Proof: If the theorem does not hold, then $d^-(v_1) \neq 0$. Suppose $N^-(v_1) = \{v_{i_1}, v_{i_2}, \dots, v_{i_r}\}$ ($r \geq 1$) represents the set of vertices whose arcs connecting v_1 direct to v_1 (exactly opposite to how we define set N^+). Now consider the vertices in set $N^-(v_1)$, suppose v_{i_1} is the vertex with the largest outdegree. As proved in Theorem 2.2, every vertex in the set $N^-(v_1)$ can be reached by v_{i_1} through a path of length at most two. Besides, through arc (v_{i_1}, v_1) , vertex v_1 can be reached, and for vertices other than v_1 and those in set $N^-(v_1)$, they can also be reached by passing through v_1 at exactly a length of 2. Therefore, v_{i_1} also satisfies the condition to be a King Chicken, which contradicts the supposition that there is only one King Chicken. Therefore, the theorem is again successfully proved by contradiction.

2.3 Hamiltonian Problem

A *Hamiltonian path* refers to a graph path between two vertices of a graph that visits each vertex exactly once. If a Hamiltonian path exists whose end-points are adjacent, then the resulting graph cycle is called a *Hamiltonian cycle*.^[1] Hamiltonian paths and cycles have special characters in tournaments since they are directed, and there are especially several previously proved theorems that we will explore here.

Theorem 2.5 (Havet, Frédéric, and Stéphan Thomassé): Every tournament T has a directed Hamiltonian path.^[6]

Proof: Let T be a tournament with n vertices. We induct on n . When $n = 1, 2$, or 3 , the result is trivially true. For $n \geq 4$, assume that the result is true for all tournaments with fewer than n vertices. Let v be any vertex

of T . Then $T - v$ is a tournament with $n - 1$ vertices and by induction hypothesis it has a directed Hamiltonian path, say $P = v_1 v_2 \dots v_{n-1}$. In case there is an arc from v to v_1 , then $P_1 = v v_1 v_2 \dots v_{n-1}$ is a directed Hamiltonian path in T . Similarly, if there is an arc from v_{n-1} to v , then $P_2 = v_1 v_2 \dots v_{n-1} v$ is a directed Hamiltonian path in T . Now, assume there is no arc from v to v_1 and no arc from v_{n-1} to v . Then there is at least one vertex w on the path P with the property that there is an arc from w to v and w is not v_{n-1} . Let v_i be the last vertex on P having this property, so that the next vertex v_{i+1} does not have this property. Then there is an arc from v_i to v and an arc from v to v_{i+1} , as shown in the graph followed. Therefore, $Q = v_1 v_2 \dots v_i v v_{i+1} v_{i+2} \dots v_{n-1}$ is a directed Hamiltonian path in T , and the theorem is thus successfully proved by induction.

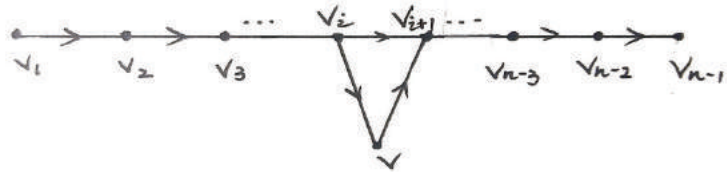


Figure 3.

Add a new vertex in original Hamiltonian path

The next proved theorem related to Hamiltonian cycle gives us a hint on its relation between the digraph's connectivity.

Theorem 2.6: A tournament has a Hamiltonian cycle if and only if it is strongly connected.^[7]

Proof: *Necessity:* If the tournament has a Hamiltonian cycle, it is strong because there is a path along the Hamiltonian cycle between any two vertices.

Sufficiency: If the tournament is strong, then we can also show it has a Hamiltonian cycle. Because the tournament is strong, it contains some cycle $C = c_1, c_2, \dots, c_n, c_1$. If there is some vertex v not on the cycle, and arcs exist (c_j, v) and (v, c_k) for some j and k , then we can find a value of i such that the arcs (c_i, v) and (v, c_{i+1}) exist using the same method as in the prior proof. Thus $C' = c_1, c_2, \dots, c_i, v, c_{i+1}, \dots, c_n, c_1$ is a longer

cycle. On the other hand, if there are vertices not on the cycle, but none such as the vertex v just described above, then it must be the case that all vertices not on the cycle are in one of two sets. One set is the successors of the cycle, where those vertices have arcs from all the vertices on the cycle. The other set is the predecessors of the cycle, where those vertices have arcs direct to all vertices on the cycle. Since the graph is strongly connected, any path from a successor to a predecessor must have an arc that leads from a successor s to a predecessor p . Then $C'' = c_1, c_2, \dots, c_n, s, p, c_1$ is a longer cycle including s and p . Thus, so long as a cycle does not include all the vertices, it can be made longer by adding vertices into the cycle through the manipulation above. Therefore, a Hamiltonian cycle must exist if the graph is strongly connected, which completes the proof.

2.4 Tournament and Connectivity

In the previous section, we have already given the basic definition and some related properties between directed graphs and connectivity. As a special kind of directed graph, a tournament demonstrates more specific conclusions related to connectivity that are worth exploring.

There is one particularly important proved theorem that concerns the strongly connected component. This will lay a solid foundation for our innovative exploration in the section that follows.

Theorem 2.7: For a tournament T , it contains a strongly connected component of order 3 if and only if there exist two vertices v and v' that $d^+(v) = d^+(v')$.

Proof: *Necessity:* We can prove this hand by proving the converse-negative proposition and induction. That is, if there does not exist two vertices v and v' that $d^+(v) = d^+(v')$, then there cannot be a strongly connected component of order 3.

We know that the outdegree of a vertex ranges from 0 to $n-1$ and the total outdegree of the tournament equals $\frac{1}{2}n(n-1)$, the total the number of arcs in the tournament, which is the also the sum of 0 to $n-1$. Since every vertex has a different outdegree, these n vertices' out-degree can only be from 0 to $n-1$, each appears exactly once.

For $n = 3$, if the three vertices have degree 0, 1, 2 respectively, it is not strongly connected. If the converse-negative proposition holds for the tournament of order n , then for tournament T of order of $n + 1$, the outdegree of their vertices should be from 0 to n respectively. Suppose $d^+(v_0) = k$, then delete the vertex v_0 and arcs connecting it and consider the new graph $T - v_0$ of order n , as the supposition goes, it does not contain a strongly connected component of order 3. Now add the vertex v_0 back; since the indegree of v_0 is zero, it cannot be in a strongly connected component of order 3. However, $T - v_0$ also does not contain a strongly connected component of order 3, so there cannot be a strongly connected component of order 3 in T . Thus, the induction is complete.

Sufficiency: For the arc linking v and v' , suppose it directs from v to v' . Suppose the arcs direct from v' direct to v_1, v_2, \dots, v_k , where $k = d^+(v')$. If there is not an arc to v directed from v_1 to v_k , then the direction of all arcs linking v and v_1, v_2, \dots, v_k must direct from v , contributing to v' 's out-degree by k . Since (v, v') also directs from v , $d^+(v) \geq k + 1 > k = d^+(v')$, contradicting the supposition. Therefore, there must be at least on arc linking v_m ($1 \leq m \leq k$) and v that directs to v . Then, v, v' and v_m form a directed cycle, which is definitely a strongly connected component of order 3. Thus, the proof is complete.

3. Bidirectional Tournament

In the previous discussion, we showed that a tournament has a variety of useful properties related to other kinds of graphs including being Hamiltonian. However, in this section, we are going to further explore a kind of special tournament graph and discover its properties. In the original tournament graph, each arc is only *unidirectional*, which means that each arc only has one direction. But what about breaking this tradition and adding another direction to the arc to makes it *bidirectional*?

In this section, we define a *bidirectional arc* as an arc that has both directions. Actually, it functions the same as two arcs of opposite directions linking the same two vertices in a digraph. However, since a tournament graph only allows one arc linking two vertices, we will have to adapt to its demand. In addition, we define the *bidirectional tournament* (BT) to be a connected digraph with exactly one arc connecting every two of its vertices, and with at least one of those arcs being bidirectional.

If there are n bidirectional arcs in such a graph, we define the graph to be a *n-bidirectional tournament* (also abbreviation n -BT for convenience). In the parts that follow, we will focus on 1-bidirectional tournaments (1 -BT) and n -bidirectional tournaments (n -BT).

We should have also noticed that with the addition of just one bidirectional arc, a lot of properties that a tournament possesses will change accordingly. Even some of the basic properties we have proven before will not hold in this section. This phenomenon will especially apply to the bidirectional arcs that greatly affect properties related to paths, cycles as well as the connectedness of BT, so these are the areas we will put more emphasis on in the following exploration.

To more deeply understand the essence of the bidirectional tournament, we will first discuss theorems and properties about the 1 -BT and explore its transformation process.

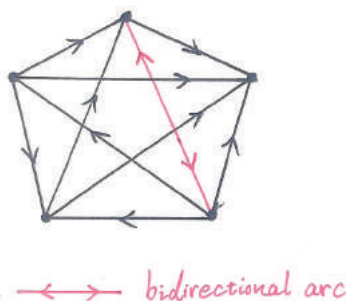


Figure 4.
Example of a bidirectional graph

3.1 Introduction to Bidirectional Tournament

If following the first two sections' pattern, we will first introduce some of the graph's properties and prove some interesting theorem. However, for this part's exploration, readers can dig deeper into this type of graph and understand its core in a different angle.

Let us reconsider the basic Theorem 1.1. This theorem even may not hold with the addition of this bidirectional arc because each arc now may contribute up to two directions.

But for connectedness, we should notice something important—that is, we can now obtain a strongly connected component of order only 2, which is not possible in a simple tournament discussed above.

Therefore, with these vague understandings of a BT, we will start the exploration first in its transformation process.

3.2 The Transformation of Bidirectional Tournament

Transformation will help us to get to the core of bidirectional graph, because in the research of connectedness and DAG as mentioned earlier, the bidirectional graph can be greatly simplified to help us prove some related theorems.

In a 1-BT, consider the vertices v and u that are connected by the bidirectional arc. In some cases, v and u can be seen as 1 vertex because they are mutually directed, so if a vertex can reach u , it certainly can also reach v . When exploring the property of strong connectedness and DAG, these two strongly connected vertices can be seen as only one vertex and that will make no difference. The process possesses similarities to the contraction process^[8] in the graph theory but also has its uniqueness when adapted to the bidirectional tournaments. The following will show exactly how to transform a BT graph.

Suppose we have a 1-BT of order $n(n > 2)$ with u and v connected by bidirectional arc. We can simplify the graph by doing the following steps.

1. Use a vertex V to combine u and v in the original 1-BT
2. For each vertex w in the original graph besides u and v , if both arcs connecting uw and vw directs from w to u and v , then in the new graph, draw an arc directly from w to V in the new graph; if both arcs connecting uw and vw directs to u and v from w , then in the new graph, draw an arc directly from V to w in the new graph; if one of the arcs directs to w , and another arc directs from u , then in the new graph draw a bidirectional graph between w and V . Specifically if there is also an arc connecting wv or wu that is bidirectional, then in the new graph we still draw a bidirectional arc connecting w and V .
3. For the rest of the arcs connecting vertices other than u or v , keep them to the new graph with original directions.

These three steps will complete a transformation and by doing so, the order of the graph actually goes down by 1—that is how the transformation brings about a simpler graph. The graph after transformation may also be a BT because step 2 may produce new bidirectional arcs, maybe more than one, so the new graph may not still be 1-BT. If the new graph is still a BT, we can repeat this process, and the new theorem following proves what will the graph be finally transformed into.

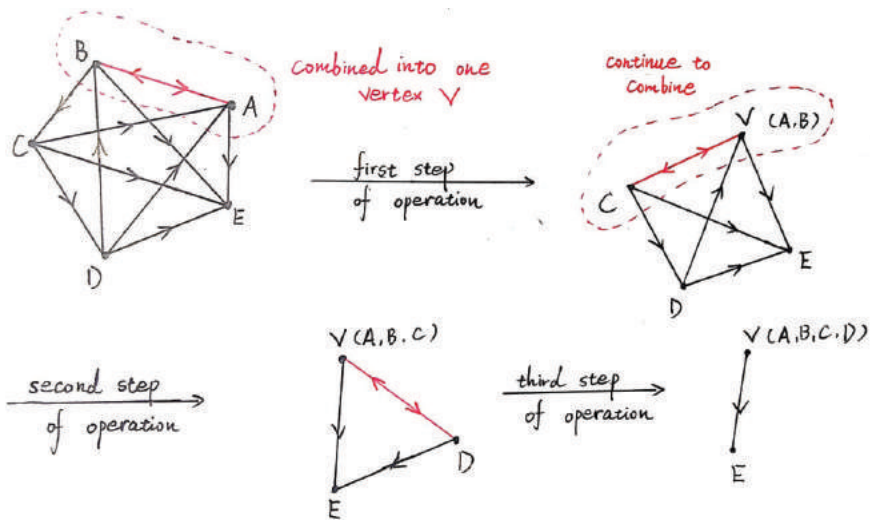


Figure 5.
Transformation process of **BT**

Theorem 3.1: After maximum times of transformation, the graph will finally be transformed into a simple tournament graph or two vertices that are connected.

The proof of this is relatively simple because if the graph is still a BT, the steps above can be repeated and the order of the graph will decrease by 1 constantly after each round of transformation. If the graph operated always has a bidirectional arc, then its order will finally be reduced to 2. If after certain times of transformation there is no bidirectional arc left, then the graph becomes a simple tournament.

Note: All the theorems in the following sections of the paper are new results which has not been systematically explored or proved by others before.

3.2.1 Theorems Relating to the Transformation

For the transformation related to the 1-BT graph, there are some interesting theories that may seem easy but are, in fact, difficult to prove. In the previous discussion, we define the transformation process by combining only one vertex each time even if there may be more than one bidirectional arc in the a processed BT. This may lead to the question of whether the choosing priority will affect the final graph we get. The next new theorem will provide an answer for that.

Theorem 3.2: The final graph we get after maximum times of transformation on 1 – BT is unique.

Proof: Firstly, we will prove in each BT graph we get after limited times of transformation on the 1 – BT, there cannot be two bidirectional arcs without common vertices. For the first time of transformation, it is definitely true. Then let us suppose after limited times of transformation this conclusion also holds true for the transformed graph with combined vertex V . Let V bidirectionally connect v_1, v_2, \dots, v_n . Then if we combine v_i and V into V' in the next step of transformation, then all the bidirectional arcs must connect with V' , so the conclusion also hold true for the next step of transformation. Therefore, by induction, this small conclusion is completed.

Next, to determine whether the final graph we get is unique, we will only need to prove if the order of vertices we process will affect the final result. For the BT graph with combined vertex V who is bidirectionally connected with v_1, v_2, \dots, v_n , let us consider the vertices besides V, v_1, v_2, \dots, v_n . Let all these other vertices form a set $U = u_1, u_2, \dots, u_n$. For the bidirectional arc connecting V and v_p and bidirectional arc connecting V and v_q , let us consider whether their combining order will affect the result. For any vertex u_i in set U , if all three arcs connecting u_i and v_p, v_q, V are of the same direction, then after v_p and v_q are combined with V , no matter the order, u_i will not be bidirectionally connected. On the other hand, if all three arcs connecting u_i and v_p, v_q, V have different directions, then after v_p and v_q are combined with V , no matter to order, u_i will be bidirectionally connected. Therefore, we can see the order of the vertices combined is unrelated to whether an additional vertex in U will be bidirectionally connected or not. If for any two of the bidirectionally connected vertices v_p and v_q it is the case, then for v_1, v_2, \dots, v_n this statement will also hold true because any two vertices can change order and the graph we get after limited step is the same so the order here does not matter. Therefore, the proof is completed.

With this theorem, we can actually simplify the transformation process by doing the following:

If there is more than one vertex, v_1, v_2, \dots, v_n , connected with the combined vertex V , then in the next step of transformation, we can combine all the $n+1$ vertices v_1, v_2, \dots, v_n and V into one vertex V' (instead of one at a

time). Now consider the vertices other than those combined and let us use u_i for illustration. If all the arcs of u_i direct to vertices combined in V' , then link the arc connecting u_i and V' from u_i to V' . If all the arcs of u_i are directed from vertices combined in V' , then link the arc connecting u_i and V' from V' to u_i . Otherwise, if arcs between u_i and V' have different directions, then connect u_i and V' with a bidirectional arc.

This can greatly simplify the transformation while guaranteeing that the final tournament we get after maximum times of transformation is still the same as we get from combining the vertices one by one, with Theorem 3.2 as backup.

3.2.2 Critical Situations

Next, we will start to discuss the situations where BT will turn into a simple tournament. The key is that in step 2, no new bidirectional arc should be produced. Therefore, for any vertex, its arcs should both be directed to or from the two bidirectionally connected vertices. This can be divided into the following 3 situations: all other arcs incident to u or v are directed towards u or v ; all other arcs incident to u or v are directed from u and v ; or there are some arcs incident to u or v that are directed towards u or v and some arcs incident to u or v that are directed away from u or v . We should notice that in any one of these three situations, for any vertex besides u and v , both of its arcs incident to u and v must possess the same direction. These three situations are shown in Figure 6.

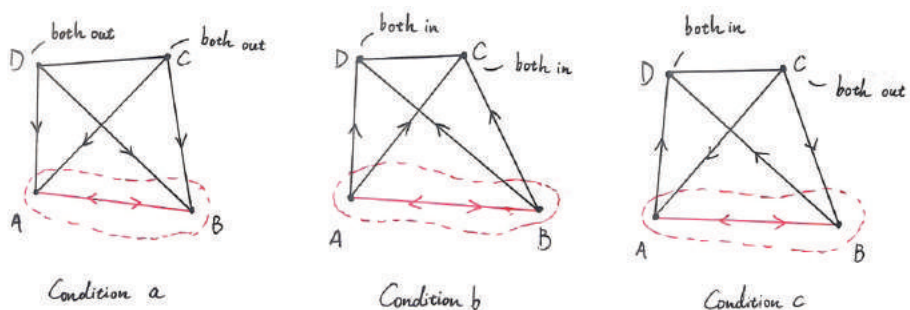


Figure 6.

Three critical situations

Let us call these three situations *critical situations*.

After we finally get a simple tournament, consider the vertices that we have previously combined into one. In another way to say it, they are also the vertices that have ever been connected by bidirectional arcs. The next new theorem will prove one of their properties in connectedness.

Theorem 3.3: All the vertices that have been combined form a strongly connected component in the original BT. Particularly, if after limited times of transformation the graph can be transformed into 2 vertices linked bidirectionally, then the original BT must be strongly connected.

Proof: For the proof of this theorem, we will use induction. For the vertices u and v connected bidirectionally in the original graph, they are strongly connected. Suppose they combine into a new vertex V_1 . After the first round of transformation, if there exists a vertex w that is connected bidirectionally with V_1 in the new graph, then w must be able to go directly to or from the original strongly connected component formed by u and v . Therefore, u , v and w together is also a strongly connected component. V_1 and w can go on to combine into V_2 and continue the transformation. The vertices combined into V_2 form a strongly connected component in the original 1-BT.

Suppose vertices combined into V_k also form a strongly connected component in the original 1-BT. Then for the vertices connected bidirectionally with V_k in the operated BT graph, they and vertices combined in V_k can similarly form a larger strongly connected component because the new vertices added and vertices that have been combined can be reached mutually. Therefore, the new vertices can be combined with V_k into V_{k+1} , continuing the transformation. Therefore, for every vertex that has been newly combined during the transformation, it actually joins in and enlarges the strongly connected component of the original BT.

As for the latter statement, if the graph can be transformed into two vertices bidirectionally connected, then all the vertices in the original graph can actually be combined into a single vertex. Through the proof above, we can conclude that all these vertices are strongly connected; thus, the original 1-BT is strongly connected, which completes the proof.

However, we should note that the latter statement is not necessary for the original graph to be strongly connected. Rather, it is only the sufficient condition, as Figure 7 proves.

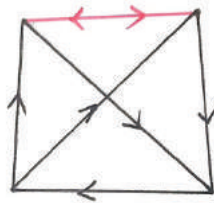


Figure 7.

*A strongly connected **BT** that cannot be transformed into two vertices linked bidirectionally*

With Theorem 3.3, we can now reconsider the critical condition. Every critical condition can actually be divided into two sets of vertices. One set is the vertices that have been already combined, which forms a strongly connected component of the original 1-BT, another is the vertices besides the combined vertex in the simple tournament after one more step of transformation.

With these two sets divided, we are prepared to move on and solve more difficult problems related to Hamiltonian path and cycle.

3.3 Hamiltonian Problems Related to Bidirectional Graph

In Theorem 2.6, we have already proved that a tournament has a Hamiltonian cycle if and only if it is strongly connected. Therefore, in critical situations, for the set of vertices combined in previous transformations, they can be drawn as a Hamiltonian cycle. Let the cycle contain vertices $V = v_1, v_2, \dots, v_p$. They form a cycle of length p , and clearly it is after $p-1$ times of transformation because originally there are two vertices that are bidirectionally connected. Let the vertices be $U = u_1, u_2, \dots, u_q$. They form a simple tournament once no more arcs can be transformed. In other words, they form a set of vertices whose induced subgraphs do not change. This is because the arcs among this group of vertices have not been changed during the transformations.

However, there is one thing unique to the graphs of critical situations. As mentioned before, after the last round of transformation to the critical BTs, no bidirectional arc shall be formed. Therefore, for each vertex in U , it either has its arcs all direct to V or directed from V . (We have only explained for any vertex in U , its arcs connecting the bidirectionally connected vertices should be of the same direction, but the bidirectionally connected vertices actually represent all the combined vertices in V ; therefore, for each vertex in U , its arcs connecting the vertices in V must all be of the same direction).

The three critical situations can thus be redrawn. Figure 8 visually depicts these critical situations for further understanding.

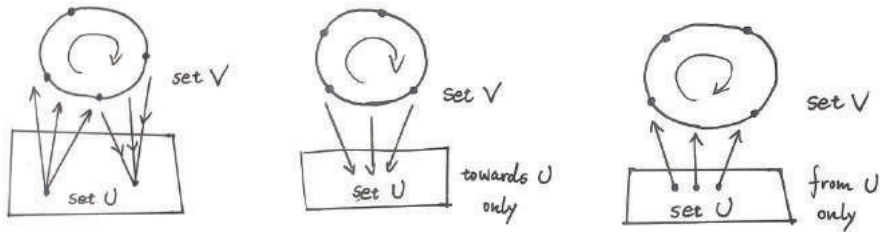


Figure 8.
Three redrawn critical situations

For the first and second situations, a small conclusion can be proved here.

Theorem 3.4: If, after limited times of transformation, the 1-BT reaches a critical situation where all the arcs connecting U and V have the same direction between these two sets, then the original graph is not strongly connected.

Proof: If all the arcs direct from U to V, then for vertices in V, they cannot reach vertices in U. If all the arcs direct from V to U, then for vertices in U, they cannot reach vertices in V. Therefore, the original 1-BT is not strongly connected.

We have already proved in Theorem 2.5 that every tournament has a directed Hamiltonian path, but for some directed graph, there is only one Hamiltonian path in the graph, as the following Figure 9 shows.

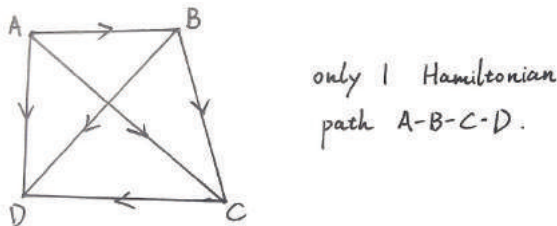


Figure 9.
Simple tournament with only one Hamiltonian path

However, with the addition of one bidirectional arc, this property can be greatly strengthened—for each 1-BT of order $n(n > 2)$, there will be at

least two Hamiltonian paths. Actually, the theorem that follows gives an even stronger conclusion that there are at least n Hamilton paths in the original $1-BT$ if it turns into a simple tournament after $n-1$ times of transformation. The proof is as the following.

Theorem 3.5: If a $1-BT$ turns into a simple tournament after $n-1$ times of transformation, then there are at least n Hamilton paths in the original $1-BT$.

Proof: After $n-1$ transformations, in total n vertices will be combined into one vertex, and according to Theorem 3.3, these combined vertices form a strongly connected component in the original graph, so they can be represented as a Hamiltonian cycle C which includes these n vertices $V = v_1, v_2, \dots, v_n$. In addition, suppose the vertices on the cycle are arranged in a way that v_i directs to v_{i+1} ($i \in 1, 2, \dots, n-1$), and especially, v_n directs to v_1 which completes the cycle as the following graphs show. The rest of the vertices, $U = u_1, u_2, \dots, u_q$, form a simple tournament T . According to the explanation above, they are thus divided in to two sets U and V , and for each vertex in U , all of its arcs connecting V either all direct to the n vertices in V or are all directed from the n vertices in V . The critical situations can be divided into the three categories discussed above:

- a. All the arcs connecting V and U direct from U to V .

Then in tournament T , according to Theorem 2.5, we can always find a Hamiltonian path. Suppose the path passes all the vertices in U in the order u_1, u_2, \dots, u_q , ending at u_q . For each arc connecting u_q and vertices in V , it directs from u_q to V and there are in total n arcs. Now we need to incorporate the vertices on the Hamiltonian cycle into the path, and we need an arc to connect C and T . If we choose an arc (u_q, v_i) as a bridge connecting these two parts, then the path can continue to go on to be $u_q, v_i, v_{i+1}, \dots, v_n, v_1, v_2, \dots, v_{i-1}$, thus forming a complete Hamiltonian path. And for choosing that bridge, there are in total n ways, and for each bridge arc chosen there is a unique corresponding Hamiltonian path. In general, the n paths are

$$u_1, u_2, \dots, u_q, v_i, v_{i+1}, \dots, v_n, v_1, v_2, \dots, v_{i-1} \quad (i \in 1, 2, \dots, n).$$

Therefore, for this situation, there are at least n Hamiltonian paths.

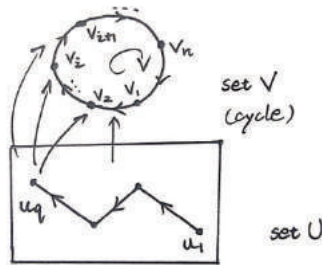


Figure 10.

Critical situation with all the arcs connecting V and U direct from U to V

b. All the arcs connecting V and U direct from V to U .

Similarly, we can find a Hamiltonian path in T . Suppose the path passes all the vertices in U in the order u_1, u_2, \dots, u_q , starting at u_1 . For each arc connecting u_1 and vertices in V , it directs from V to u_1 and there are in total n arcs. Now we need to incorporate the vertices on the Hamiltonian cycle into the path, and we need an arc to connect C and T . If we choose an arc (v_i, u_q) as a bridge connecting these two parts, then the path before can be extended as $v_{i+1}, v_{i+2}, \dots, v_n, v_1, v_2, \dots, v_{i-1}, v_i, u_1$, thus forming a complete Hamiltonian path. And for choosing that bridge, there are in total n ways, and for each bridge arc chosen there is a unique corresponding Hamiltonian path. In general, the n paths are

$$v_{i+1}, v_{i+2}, \dots, v_n, v_1, v_2, \dots, v_{i-1}, v_i, u_1, u_2, \dots, u_q \quad (i \in 1, 2, \dots, n).$$

Therefore, for this situation, there are also at least n Hamiltonian paths.

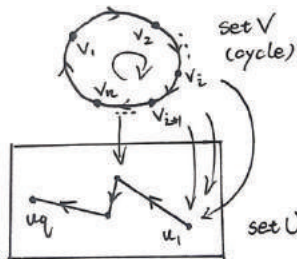


Figure 11.

Critical situation with all the arcs connecting V and U direct from V to U

c. The arcs linking U and V have different directions.

In this special case, we divide the vertices in U into two sets U_a and U_b , where $U_a = u_{a_1}, u_{a_2}, \dots, u_{a_x}$ contains all the vertices whose arcs

connecting V all direct to V , while $U_b = u_{b_1}, u_{b_2}, \dots, u_{b_y}$ contains all the vertices whose arcs connecting V all directed from V . Note that x and y satisfies $x + y = q$. Suppose the vertices in U_a form a smaller tournament T_1 , and the vertices in U_b form a smaller tournament T_2 . In T_1 , we can find a Hamiltonian path P_1 according to Theorem 2.5. Let the path connect the vertices in order $u_{a_1}, u_{a_2}, \dots, u_{a_x}$, ending with u_{a_x} . Similarly, in T_2 , we can find a Hamiltonian path P_2 . Let the path connect the vertices in order $u_{b_1}, u_{b_2}, \dots, u_{b_y}$, starting with u_{b_1} . To connect P_1, P_2 and C to form a longer Hamiltonian path, we need 2 additional bridges. For u_{a_x} , suppose it connects v_i in the cycle by arc (u_{a_x}, v_i) , then the path $v_i, v_{i+1}, \dots, v_n, v_1, v_2, \dots, v_{i-1}$ successfully passes through all the vertices on the cycle. For another bridge linking P_2 and C , both of its ends have already been determined because the arc must link the end of the path on the cycle and the start of P_2 . Therefore, only (v_{i-1}, u_{b_1}) satisfies the condition.

In short, if one bridge arc is (u_{a_x}, v_i) , then the other must be (v_{i-1}, u_{b_1}) to form a complete Hamiltonian path. For the total number of Hamiltonian paths, there are in total n ways to choose v_i , and for each way chosen there is a unique corresponding Hamiltonian path. In general, the n paths are

$$u_{a_1}, u_{a_2}, \dots, u_{a_x}, v_i, v_{i+1}, \dots, v_n, v_1, v_2, \dots, v_{i-1}, u_{b_1}, u_{b_2}, \dots, u_{b_y} \quad (i \in 1, 2, \dots, n).$$

Therefore, for this situation, there are also at least n Hamiltonian paths.

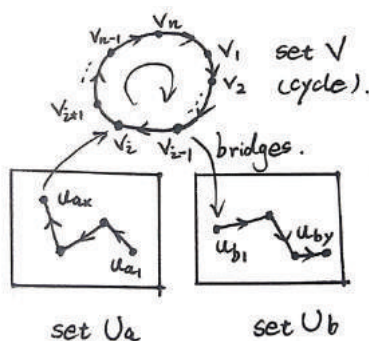


Figure 12.

Critical situation with arcs linking U and V have different directions

We should also notice that, in the condition c above, if the arc connecting u_{a_1} and u_{b_y} directs to u_{a_1} , then we can actually get a Hamiltonian cycle. In

addition, if there is more than one Hamiltonian path in set U , then the least total number of Hamiltonian path in the $1 - BT$ graph will also double, triple, or even quadruple (for example, if there are two Hamiltonian path in both sets U_a and U_b respectively). That is because for each additional Hamiltonian path in U , we can also repeat the process mentioned above of how to combine the cycle and form a complete Hamiltonian path, and there will be at least n additional paths in total added.

3.4 N-Bidirectional Tournament and Strongly Connected Component

We have already discussed the definition of the strongly connected component (SCC) in the previous discussion. However, the counting of strongly connected components is a challenge, especially the proof related to the maximum number of strongly connected components in a tournament. The challenge can mainly be attributed to the complexity of graph construction and the proof of upper limits. In the BT, the connectedness of the graph is greatly strengthened, giving us more strongly connected components and at the same time posing to us a greater challenge. This section will mainly discuss the maximum number of different strongly connected components in an $n - BT$ graph of order n . With bidirectional arcs added, a new insight of strongly connected components can be further explored.

3.4.1 N-BT and Strongly Connected Component of Order Three

With bidirectional arcs, the connectedness of the graph is greatly strengthened, so when we are exploring the maximum number of the strongly connected component, it is always easier to look at the opposite side of the question—when can the three vertices not be strongly connected?

This problem can be divided in to the following two situations:

- A. There exists a vertex, whose arcs linking the other two vertices are both unidirectional and direct out from this vertex.
- B. There exists a vertex, whose arcs linking the other two vertices are both unidirectional and direct to this vertex.

Let us call these conditions *bad conditions*.

No matter if a bidirectional arc exists or not, if either one of the conditions above is satisfied, then these three vertices will not form a strongly connected component. Otherwise, it will be a strongly connected component (which has more possibilities and that is why we choose to consider the opposite side).

With this in mind, we can explore the following problem now.

Problem 3.1: What is the maximum number of strongly connected components of order three in a n -BT graph of order n ($n > 2$)?

First, we will explore the number when n is small enough.

If $n = 3$, there should be three bidirectional arcs in the graph and since there are only three arcs, the graph must be strongly connected, the answer is 1.

If $n = 4$, there should be four bidirectional arcs in the graph, and all of its subgraphs of order 3 can be strongly connected components. The construction is as follows:

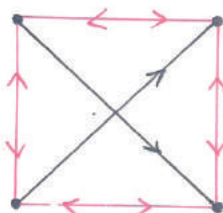


Figure 13.
Construction for $n = 4$

Therefore, the answer for $n = 4$ is 4.

If $n = 5$, similarly we can construct a graph with all the subgraphs of order 3 being strongly connected components.

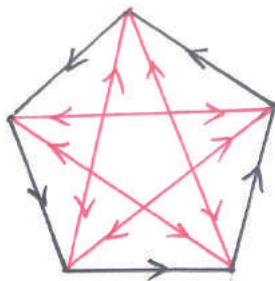


Figure 14.
Construction for $n = 5$

Therefore, the answer is 10.

For $n > 5$, things will get more difficult to analyze and that is where the true challenge starts, because if $n = 6$, we cannot construct a graph whose subgraphs of order 3 are all strongly connected components. Therefore, its maximum number needs rigorous proof.

For our later discussion, our mission is to minimize the number of the subgraphs that are not strongly connected. Let α be the set of the group of vertices of order 3 that satisfy bad condition A. Suppose the number of the bad condition A mentioned above is $|\alpha|$. Similarly, let β be the set of the group of vertices of order 3 that satisfy the bad condition B. Suppose the number of bad conditions B mentioned above is $|\beta|$. We should notice here that conditions A and B can be both satisfied at the same time if all the three arcs connecting them are unidirectional but does not form a cycle.

Let us divide n into two categories—odd and even, and we will start with a relatively easy part.

Condition 1: Consider $n = 2k + 1 (k > 2)$.

Step 1: Prove the upper limit.

There should be $2k + 1$ bidirectional arcs in total, so the number of unidirectional arcs should be $\binom{2k+1}{2} - (2k+1) = (2k+1)(k-1)$. Suppose the vertices are v_1, v_2, \dots, v_n , then the sum of their outdegree except the bidirectional arcs should be the number of unidirectional arcs because each unidirectional arc contributes to one indegree. Here let us define $d^+(v_i)$ to be the outdegree of vertex v_i only contributed by unidirectional arcs, but not bidirectional arcs. Then, we have

$$\sum_{i=1}^n d^+(v_i) = (2k+1)(k-1).$$

Let us now consider the least number of the bad condition A.

For any vertex v_i , suppose all its unidirectional arcs pointing out direct to a set of vertices $N = \{u_1, u_2, \dots, u_p\}$ (where $p = d^+(v_i)$). For any two of the vertices in N and v_i , the three of them cannot form a strongly connected component of order 3 because bad condition A is satisfied, with both unidirectional arcs directing out from v_i . Therefore, for each vertex v_i , the total number of the bad condition A should be $\binom{d^+(v_i)}{2}$. Therefore, the total number of bad conditions generated by bad condition A should be $\sum_{i=1}^n \binom{d^+(v_i)}{2}$.

We should notice that for each vertex v_i , the bad condition A will not repeat on the same set of three vertices because there cannot be a subgraph of order 3 that has two vertices whose arcs are both directing out. Therefore, we can simply add the bad condition A for all vertices and we get

$$|\alpha| = \sum_{i=1}^n \binom{d^+(v_i)}{2} = \sum_{i=1}^n \frac{d^+(v_i) \times (d^+(v_i) - 1)}{2} = \frac{1}{2} \sum_{i=1}^n (d^+(v_i))^2 - \frac{1}{2} \sum_{i=1}^n d^+(v_i).$$

Since we have already known $\sum_{i=1}^n d^+(v_i) = (2k+1)(k-1)$, the equation can be further simplified as

$$|\alpha| = \frac{1}{2} \sum_{i=1}^n (d^+(v_i))^2 - \frac{1}{2} (2k+1)(k-1).$$

To further calculate the minimum value of $|\alpha|$, we have to apply *Mean Power Inequality*^[9] as the following

$$\left(\frac{\sum_{i=1}^n a_i^p}{n}\right)^{\frac{1}{p}} \geq \left(\frac{\sum_{i=1}^n a_i^q}{n}\right)^{\frac{1}{q}}, \text{ for } a_i > 0 \text{ and } p > q.$$

(Equality can be achieved if and only if $a_1 = a_2 = \dots = a_n$)

Here, let $p = 2$ and $q = 1$, and apply this inequality to our current formula to get the lower bound of $|\alpha|$. We can thus get

$$\frac{1}{2} \sum_{i=1}^n (d^+(v_i))^2 \geq \frac{1}{2} \times n \times \left(\frac{\sum_{i=1}^n d^+(v_i)}{n}\right)^2 = \frac{(\sum_{i=1}^n d^+(v_i))^2}{2n} = \frac{(2k+1)^2 (k-1)^2}{2n}.$$

Since $n = 2k+1$, the formula above can be further simplified as

$$\frac{1}{2} \sum_{i=1}^n (d^+(v_i))^2 \geq \frac{(2k+1)^2 (k-1)^2}{2n} = \frac{(2k+1)^2 (k-1)^2}{2(2k+1)} = \frac{(2k+1)(k-1)^2}{2}.$$

We should be aware that the equal sign can be achieved if and only if $d^+(v_1) = d^+(v_2) = \dots = d^+(v_n)$. Since $\sum_{i=1}^n d^+(v_i) = (2k+1)(k-1)$, the requirement for equality is just $d^+(v_1) = d^+(v_2) = \dots = d^+(v_n) = k-1$.

Therefore, we can calculate the minimum of $|\alpha|$:

$$\begin{aligned} |\alpha| &= \frac{1}{2} \sum_{i=1}^n (d^+(v_i))^2 - \frac{1}{2} (2k+1)(k-1) \geq \frac{(2k+1)(k-1)^2}{2} - \frac{(2k+1)(k-1)}{2} \\ &= \frac{(2k+1)(k-1)(k-2)}{2} = (2k+1) \binom{k-1}{2}. \end{aligned}$$

Therefore, the total number of the bad condition A should be at least $(2k+1)\binom{k-1}{2}$, and this minimum value can be achieved if and if only $d^+(v_1) = d^+(v_2) = \dots = d^+(v_n) = k-1$.

On the other hand, there are in total $\binom{n}{3} = \binom{2k+1}{3}$ subgraphs of order 3 in the BT of order n ; therefore, the total number of strongly connected component of order 3 cannot exceed

$$\binom{2k+1}{3} - (2k+1)\binom{k-1}{2}.$$

The proof of the upper limit of the strongly connected component of order 3 for odd number n is thus completed.

We have not considered bad condition B for now; however, through careful construction, we can let all the bad condition B coincide with bad condition A to guarantee that no more bad conditions will be further generated (notice that bad conditions A and B can appear at the same time). The proof will later appear in the construction part.

Step 2: Construct a graph that satisfies that there are $\binom{2k+1}{3} - (2k+1)\binom{k-1}{2}$ strongly connected components of order 3 in a n -BT of order n when n is odd.

This is the key part which needs some inspiration and patience to discover. The construction is a relatively technical one.

Place the n vertices $v_1, v_2, \dots, v_{2k+1} = v_n$ equally spaced on a circle (counterclockwise in order). Next, let all the main (longest) diagonals of this regular polygon be the bidirectional arcs. We should notice here since n is odd, there are actually 2 main diagonals for one vertex, and since each diagonal connects 2 vertices, the total number of bidirectional arcs is exactly n . The n bidirectional arcs should be $v_i v_{i+k}$ (if $i+k > 2k+1$, then $v_{i+k} = v_{i-k-1}$). Then for each vertex v_i , let the arcs connecting v_i and $v_{i+1}, v_{i+2}, \dots, v_{i+k-1}$ (the next $k-1$ vertices from v_i counterclockwise, and if $i+k-1 > 2k+1$, $v_{i+k-1} = v_{i-k-2}$) be unidirectional and direct out from v_i , and let the arcs connecting v_i and $v_{i-1}, v_{i-2}, \dots, v_{i-k+1}$ (the next $k-1$ vertices from v_i clockwise, and if $i-k+1 < 1$, $v_{i-k+1} = v_{i+k+2}$) be unidirectional and direct to v_i .

In short, the core of this construction includes just 2 steps.

1. Connect all the main diagonals with a bidirectional arc.
2. For each vertex, let the all its arcs connecting vertices on the right side of the bidirectional arc direct out, and let the all its arcs connecting vertices on the left side of the bidirectional arc direct in.

The following Figure 15 will show this construction in detail. In addition, we may note that the set of bidirectional arcs form a 2-factor in constructions for any odd n .

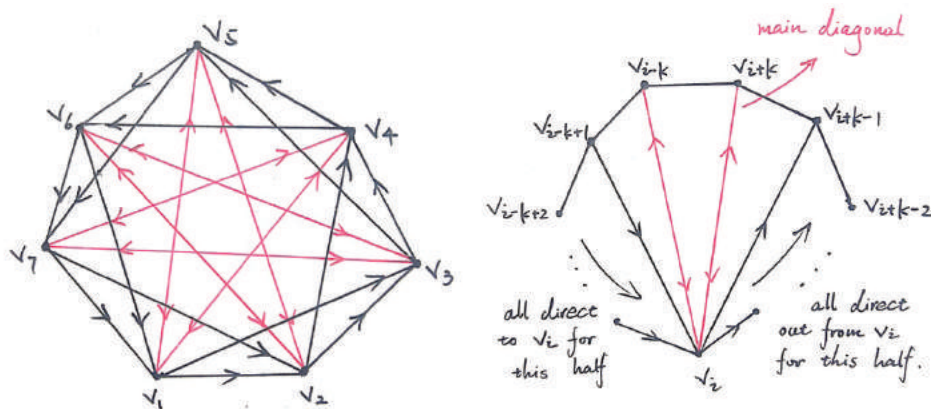


Figure 15.
The construction for n is odd

We now need to prove why this n -BT satisfies that there are $\binom{2k+1}{3} - (2k+1)\binom{k-1}{2}$ strongly connected components of order 3. First, as the requirement for equality to be achieved shows, every vertex should have $k-1$ arcs directing out because $d^+(v_1) = d^+(v_2) = \dots = d^+(v_n) = k-1$. For each vertex in the graph, the number of arcs directing out is exactly $k-1$, thus satisfies the requirement. Next, we need to prove that no additional bad condition B that does not coincide with bad condition A exists. For a bad condition B that includes three vertices v_i, v_a and v_b , let v_i be the vertex that has both arcs $(v_a, v_i), (v_b, v_i)$ directing to itself. Therefore, according to the construction, v_a and v_b should be both within the next $k-1$ vertices counting clockwise from v_i . Suppose v_a is nearer to v_i , then the direction of the arc connecting v_a and v_b must direct from v_b because v_a must be within the $k-1$ vertices counting counterclockwise from v_b . Therefore, this subgraph of order 3 is also a bad condition A because both arcs of v_b are directing out, so it has been counted already. Thus, no additional conditions of bad condition B should be considered again.

Also, since all the bidirectional arcs are the main diagonals, and based on the arrangement of the unidirectional arcs, there cannot be a bad condition that involves a bidirectional arc. (As the example about v_i , v_a , and v_b above indicates, the arc connecting v_a and v_b cannot be a bidirectional arc since v_a must be within the $k - 1$ vertices counting counterclockwise from v_b).

Therefore, this construction satisfies that only bad condition A should be counted and thus the maximum number of strongly connected components of order 3 is

$$\binom{2k+1}{3} - (2k+1)\binom{k-1}{2}.$$

Now we may start to wonder why we have to divide the odd and even orders into different conditions. The following discussion may resolve this confusion.

Condition 2: Consider $n = 2k(k > 2)$.

Step 1: Prove the upper limit.

We repeat this process similarly. There should be $2k$ bidirectional arcs in total, so the number of unidirectional arcs should be $\binom{2k}{2} - 2k = k(2k - 3)$.

Notice that this is not a multiple of $2k$, and that is why trouble arises when calculating an upper limit. We will first just analyze as above. Suppose the vertices are v_1, v_2, \dots, v_n , then we have

$$\sum_{i=1}^n d^+(v_i) = k(2k - 3).$$

Let us now consider the least number of groups of three vertices that satisfy bad condition A.

Similarly, for each vertex v_i , the total number of groups of three vertices that satisfy bad condition A should be $\binom{d^+(v_i)}{2}$. Therefore, the total number of bad conditions generated by bad condition A should be $\sum_{i=1}^n \binom{d^+(v_i)}{2}$.

We should notice that for each vertex v_i , the bad condition A will not repeat because there cannot be a subgraph of 3 that has two vertices whose arcs both directing out. Therefore, we can simply add the bad condition A for all vertices and we get

$$|\alpha| = \sum_{i=1}^n \binom{d^+(v_i)}{2} = \sum_{i=1}^n \frac{d^+(v_i) \times (d^+(v_i) - 1)}{2} = \frac{1}{2} \sum_{i=1}^n d^+(v_i) \times (d^+(v_i) - 1).$$

We know that in order for the power mean inequality to achieve the equal sign, the requirement is for $d^+(v_1) = d^+(v_2) = \dots = d^+(v_n)$. However, the sum of these n terms is not a multiple of $2k$. Since $d^+(v_1), d^+(v_2), \dots, d^+(v_n)$ must all be integers, the equal sign cannot hold in this condition. Therefore, this method cannot hold in this situation. Another method is needed. The lemma we proved next will provide a hint.

Lemma: For any convex function $f(x)$, if the sum of x_1, x_2, \dots, x_n (all of them integers) is determined, $f(x_1) + f(x_2) + \dots + f(x_n)$ will achieve the minimum value if the difference of any two of $f(x_1), f(x_2), \dots, f(x_n)$ is always less than or equal to 1.

Proof: A convex function $f(x)$ indicates that as the variable x increases at a constant rate, $f(x)$ increases faster and faster. Therefore, for any x_1 and x_2 , if their sum is already determined, then for $f(x_1) + f(x_2)$ to be as small as possible, x_1 and x_2 should be as close as possible, and when $x_1 = x_2$, the minimum value can be achieved, as the following Figure 16 indicates. If for x_1 and x_2 this is the case, then for x_1, x_2, \dots, x_n it also holds. If the sum of these n variables is determined, then for $f(x_1) + f(x_2) + \dots + f(x_n)$ to be as small as possible, x_1, x_2, \dots, x_n should be as close as possible, and when they are all equal, the minimum value can be achieved. That is actually an insight into the power mean inequality used before about how to achieve the equality.

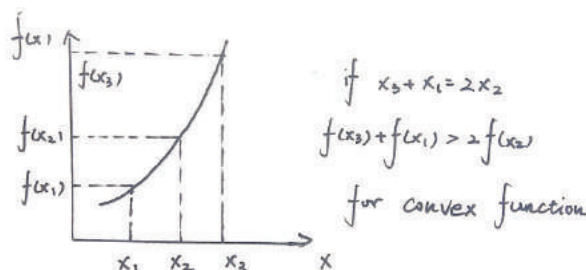


Figure 16.

The illustration of power mean inequality and property of convex function

To prove the later statement that the difference of these n variables will not exceed 1, we will use contradiction. If there exist two variables x_a and x_b ($x_a > x_b$) whose difference is equal to or greater than 2 and the sum of $f(x_1), f(x_2), \dots, f(x_n)$ is minimal, then we can always replace x_a and x_b with $x_a - 1$ and $x_b + 1$, keeping their sum the same while $f(x_1) + f(x_2) + \dots + f(x_n)$ decreases, which contradicts our supposition. Therefore, when $f(x_1) + f(x_2) + \dots + f(x_n)$ achieves the minimal value after adjustment, the difference between any two of $f(x_1), f(x_2), \dots, f(x_n)$ should not be more than one.

Now we will come back to our challenge. Similarly, we construct a function $f(x) = x(x-1)$. For $x > 1$, the graph of the function is convex. Let each x_i proved in the lemma above correspond to $d^+(v_i)$. According to the lemma, x_1, x_2, \dots, x_n should still be as close as possible even though they cannot be all the same. Since their sum is $k(2k-3)$ which is known already, to minimize $f(x_1) + f(x_2) + \dots + f(x_n)$, the difference of any two of $f(x_1), f(x_2), \dots, f(x_n)$ should not be more than 1. Therefore, there is only one way that satisfies this condition in order for $f(x_1) + f(x_2) + \dots + f(x_n)$ to be minimal: half of x_1, x_2, \dots, x_n should be $k-1$ and another half of them should be $k-2$.

Therefore,

$$\begin{aligned} |\alpha| &= \frac{1}{2} \sum_{i=1}^n d^+(v_i) \times (d^+(v_i) - 1) \geq \frac{1}{2} k(k-1)(k-2) + \frac{1}{2} k(k-2)(k-3) \\ &= k \binom{k-1}{2} + k \binom{k-2}{2}. \end{aligned}$$

Therefore, the total number of bad condition A should be at least $k \binom{k-1}{2} + k \binom{k-2}{2}$, and this minimum value can be achieved if and if only half of $d^+(v_1), d^+(v_2), \dots, d^+(v_n)$ are equal to $k-1$ and another half of them are equal to $k-2$. On the other hand, there are in total $\binom{n}{3} = \binom{2k}{3}$ subgraphs of order 3 in the BT of order n ; therefore, the total number of strongly connected components of order 3 cannot exceed

$$\binom{2k}{3} - k \binom{k-1}{2} - k \binom{k-2}{2}.$$

The proof of the upper limit of the number strongly connected components of order 3 for even n is thus also completed.

Step 2: Construct a graph that satisfies that there are $\binom{2k}{3} - k \binom{k-1}{2} - k \binom{k-2}{2}$ strongly connected components of order 3 in a n -BT of order n when n is even.

The train of thought is similar to that when n is odd. However, the construction is a little different because for n to be even, there is only one main diagonal for each vertex.

Place the n vertices v_1, v_2, \dots, v_{2k} (v_n) equally spaced on a circle (counterclockwise in order). Next, let all the main diagonals of this regular polygon be the bidirectional arc. However, there are still half of the bidirectional arcs missing.

Let all the arcs $v_i v_{i+k-1}$ (if $i+k-1 > 2k+1$, $v_{i+k-1} = v_{i-k-2}$) also be the bidirectional arcs if i is even, and those arcs contribute to another half of the bidirectional arcs.

Then for the unidirectional arcs, the condition is slightly different when n is a multiple of 4.

a. If n can be divided by 4, then after all the bidirectional arcs have been connected, there are two bidirectional arcs for each vertex exactly. That is, the set of all bidirectional arcs also forms a 2-factor in this construction.

Then for each vertex v_i , let us connect the unidirectional arc. If i is even, let the arcs connecting v_i and $v_{i+1}, v_{i+2}, \dots, v_{i+k-2}$ (the next $k-2$ vertices from v_i counterclockwise, and if $i+k-2 > 2k+1$, $v_{i+k-2} = v_{i-k-3}$) be unidirectional and direct out from v_i , and let the arcs connecting v_i and $v_{i-1}, v_{i-2}, \dots, v_{i-k-1}$ (the next $k-1$ vertices from v_i clockwise, and if $i-k-1 < 1$, $v_{i-k-1} = v_{i+k}$) be unidirectional and direct to v_i . If i is odd, let the arcs connecting v_i and $v_{i+1}, v_{i+2}, \dots, v_{i+k-1}$ (the next $k-1$ vertices from v_i counterclockwise, and if $i+k-1 > 2k+1$, $v_{i+k-1} = v_{i-k-2}$) be unidirectional and direct out from v_i , and let the arcs connecting v_i and $v_{i-1}, v_{i-2}, \dots, v_{i-k+2}$ (the next $k-2$ vertices from v_i clockwise, and if $i-k+2 < 1$, $v_{i-k+2} = v_{i+k+2}$) be unidirectional and direct to v_i .

The following Figure 17 shows this construction in detail.

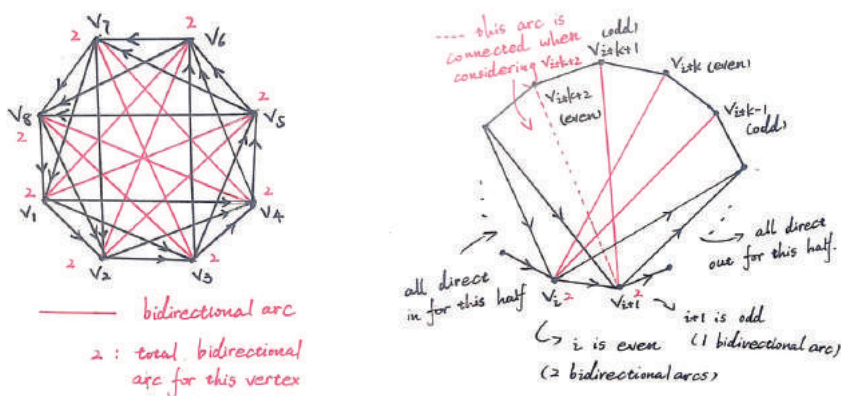


Figure 17.

Construction for even n that can be divided by 4

b. If n cannot be divided by 4, then after all the bidirectional arcs have been connected, there are three bidirectional arcs for v_i if i is even, and there is one bidirectional arc for v_i if i is odd.

Then for each vertex v_i , let us connect the unidirectional arc. If i is even, let the arcs connecting v_i and $v_{i+1}, v_{i+2}, \dots, v_{i+k-2}$ (the next $k-2$ vertices from v_i counterclockwise, and if $i+k-2 > 2k+1, v_{i+k-2} = v_{i-k-3}$) be unidirectional and direct out from v_i , and let the arcs connecting v_i and $v_{i-1}, v_{i-2}, \dots, v_{i-k+2}$ (the next $k-2$ vertices from v_i clockwise, and if $i-k+2 < 1, v_{i-k+2} = v_{i+k+2}$) be unidirectional and direct to v_i . If i is odd, let the arcs connecting v_i and $v_{i+1}, v_{i+2}, \dots, v_{i+k-1}$ (the next $k-1$ vertices from v_i counterclockwise, and if $i+k-1 > 2k+1, v_{i+k-1} = v_{i-k-2}$) be unidirectional and direct out from v_i , and let the arcs connecting v_i and $v_{i-1}, v_{i-2}, \dots, v_{i-k-1}$ (the next $k-1$ vertices from v_i clockwise, and if $i-k-1 < 1, v_{i-k-1} = v_{i+k}$) be unidirectional and direct to v_i .

The following Figure 18 shows this construction in detail.

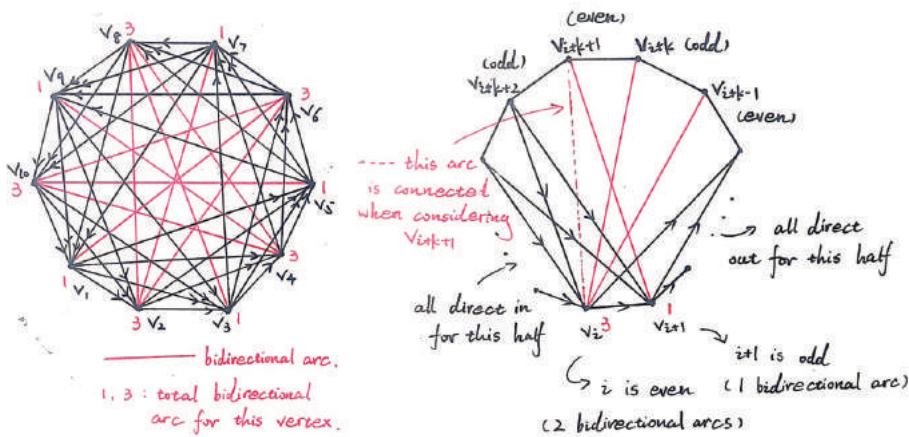


Figure 18.

Construction for even n that cannot be divided by 4

In short, the core of both of these constructions in conditions a and b can be divided into the following two steps, which is quite similar to when n is odd:

1. Connect all the main diagonals and $v_i v_{i+k-1(\text{mod } n)}$ with bidirectional arcs.
2. For each vertex, let the all its arcs connecting vertices on the right side of the bidirectional arc direct out, and let the all its arcs connecting vertices on the left side of the bidirectional arc direct in.

Both of the constructions above satisfy the requirement for $d^+(v_i)$, and it is worth noticing that the half of the vertices whose $d^+ = k-1$ and another half of vertices whose $d^+ = k-2$ are arranged in an alternating sequence.

The proof for why this construction satisfies our theorem is similar to that in condition 1. Since all the arcs connecting vertices on the right side of the bidirectional arc incident to itself direct out and all the arcs connecting vertices on the left side of the bidirectional arc incident to itself direct in, which is the same for condition 1, all the bad conditions A will coincide with bad condition B and no additional bad condition B should be considered again.

Therefore, the maximum number of strongly connected components of order 3 is

$$\binom{2k}{3} - k \binom{k-1}{2} - k \binom{k-2}{2}.$$

We may also realize now why for $n = 3, 4, 5$ all the subgraphs of order 3 can be strongly connected—because what needs to be subtracted from $\binom{2k}{3}$ or $\binom{2k+1}{3}$ is 0.

To sum up, we can get the following theorem.

Theorem 3.6 (1): The maximum number of strongly connected components of order 3 in a n -BT graph of order $n(n > 2)$ is

$$\binom{n}{3} - \frac{n}{2} \binom{\frac{n}{2}-1}{2} - \frac{n}{2} \binom{\frac{n}{2}-2}{2} \text{ if } n \text{ is even or } \binom{n}{3} - n \binom{\frac{n-3}{2}}{2} \text{ if } n \text{ is odd.}$$

Thus, we have completely solved the problem by applying algebraic inequalities and technical constructions in graph theory related to bidirectional arcs.

3.4.2 n -BT and Strongly Connected Component of Order Four

For the strongly connected component of order 4, the bad conditions will change accordingly. The difficulty seems to be increasing with more bad conditions.

- A. There exists a vertex, whose arcs linking the other three vertices are all unidirectional and direct out from this vertex.
- B. There exists a vertex, whose arcs linking the other three vertices are all unidirectional and direct to this vertex.

- C. Two of the vertices v_1 and v_2 are connected bidirectionally, and the other two vertices u_1 and u_2 are also connected bidirectionally, but the other four arcs all direct from v_1, v_2 to u_1, u_2 .

Problem 3.2: What is the maximum number of strongly connected components of order four in a n -BT graph of order $n(n > 3)$?

However, even with a new bad condition added, we can still try to calculate in the same way—by dividing n into even and odd—and then discuss the two conditions. However, this time, we can make it quick.

Condition 1: Consider $n = 2k + 1$.

Step 1: Prove the upper limit.

There should be $2k + 1$ bidirectional arcs in total, and the outdegree of all vertices should be

$$\sum_{i=1}^n d^+(v_i) = (2k + 1)(k - 1).$$

Still, we consider the least number of bad condition.

For any vertex v_p , suppose all its unidirectional arcs pointing out direct to a set of vertices $N = \{u_1, u_2, \dots, u_p\}$ (where $p = d^+(v_i)$). For any three of the vertices in N and v_p , the three of them cannot form a strongly connected component of order 4 because bad condition A is satisfied. Therefore, the total number of bad conditions generated by bad condition A should be

$$\sum_{i=1}^n \binom{d^+(v_i)}{3}.$$

$$|\alpha| = \sum_{i=1}^n \binom{d^+(v_i)}{3} = \frac{1}{6} \sum_{i=1}^n d^+(v_i) \times (d^+(v_i) - 1) \times (d^+(v_i) - 2).$$

Here, we will apply the lemma above to solve the problem. To solve the current problem, we will similarly construct a function $f(x) = x(x-1)(x-2)$. For $x > 2$, the graph of the function is convex, indicating that as the variable x increases at a constant speed, $f(x)$ increases faster and faster. As the condition 2 in the last section shows, when the sum of x_1, x_2, \dots, x_n is determined, to minimize $f(x_1) + f(x_2) + \dots + f(x_n)$, x_1, x_2, \dots, x_n should be as close as possible. Let each x_i correspond to $d^+(v_i)$. For $|\alpha|$ to be as small as

possible, the value of $d^+(v_i)$ should be all the same and as n is odd, this can be achieved.

Therefore, $|\alpha|$ achieved minimal value when $d^+(v_1) = d^+(v_2) = \dots = d^+(v_n) = k - 1$.

$$|\alpha| = \frac{1}{6} \sum_{i=1}^n d^+(v_i) \times (d^+(v_i) - 1) \times (d^+(v_i) - 2) \geq (2k + 1) \binom{k-1}{3}.$$

Thus, as there are in total $\binom{2k+1}{4}$ subgraphs of order 4, the upper limit should be

$$\binom{2k+1}{4} - (2k+1) \binom{k-1}{3}.$$

Step 2: Construct a graph that satisfies there are $\binom{2k+1}{4} - (2k+1) \binom{k-1}{3}$

strongly connected components of order 4 in a n -BT of order n when n is odd. We still construct the same graph as when n is odd in the last section.

For the proof of sufficiency, let us first prove no additional bad condition B that does not coincide with bad condition A exists. For a bad condition B that includes four vertices v_i, v_a, v_b and v_c , let v_i be the vertex that has three arcs $(v_a, v_i), (v_b, v_i), (v_c, v_i)$ directing toward it. Therefore, according to the construction, v_a, v_b and v_c should be all within the next $k - 1$ vertices counting clockwise from v_i . Suppose v_a is nearer to v_i and v_b is second nearer to v_i , then the direction of arc connecting v_c and v_a, v_b must both direct from v_c because v_a and v_b are within the next $k - 1$ vertices counting counterclockwise from v_c . Therefore, this subgraph of order 4 is also a bad condition A because all three arcs of v_c are directing out, so it has been counted already. Thus, no additional conditions of bad condition B should be considered again.

In addition, if the subgraph of order 4 contains two bidirectional arcs, bad condition C would not appear. Therefore, the maximum number of strongly connected component of order 4 is

$$\binom{2k+1}{4} - (2k+1) \binom{k-1}{3}.$$

Condition 2: Consider $n = 2k$.

Step 1: Prove the upper limit.

There should be $2k$ bidirectional arcs in total, and the outdegree of all vertices should be

$$\sum_{i=1}^n d^+(v_i) = k(2k-3).$$

Still, we consider the least number of bad conditions A.

The total number of bad conditions generated by bad condition A should

$$\text{be } \sum_{i=1}^n \binom{d^+(v_i)}{3}.$$

$$|\alpha| = \sum_{i=1}^n \binom{d^+(v_i)}{3} = \frac{1}{6} \sum_{i=1}^n d^+(v_i) \times (d^+(v_i) - 1) \times (d^+(v_i) - 2).$$

Construct a function $f(x) = x(x-1)(x-2)$. When the sum of x_1, x_2, \dots, x_n is determined, to minimize $f(x_1) + f(x_2) + \dots + f(x_n)$, x_1, x_2, \dots, x_n should be as close as possible. Let each x_i correspond to $d^+(v_i)$. However, since n is even, the value for $d^+(v_i)$ cannot be all the same since $k(2k-3)$ is not a multiple of $2k$. Therefore, for $|\alpha|$ to be as small as possible, the difference between any two of $f(x_1), f(x_2), \dots, f(x_n)$ should always be less than or equal to 1 according to the lemma. Thus, half of $d^+(v_i)$ should be $k-1$, and another half of $d^+(v_i)$ should be $k-2$.

Therefore,

$$|\alpha| = \frac{1}{6} \sum_{i=1}^n d^+(v_i) \times (d^+(v_i) - 1) \times (d^+(v_i) - 2) \geq k \binom{k-1}{3} + k \binom{k-2}{3}.$$

Thus, as there are in total $\binom{2k+1}{4}$ subgraphs of order 4, the upper limit should be

$$\binom{2k}{4} - k \binom{k-1}{3} - k \binom{k-2}{3}.$$

Step 2: Construct a graph that satisfies there are $\binom{2k}{4} - k \binom{k-1}{3} - k \binom{k-2}{3}$

strongly connected components of order 4 in a n -BT of order n when n is even.

The construction is same as that in the condition 2 of the last section. For its proof regarding why this graph still holds, it is similar to that in condition 1 of this section.

Therefore, another theorem can be thus derived from the analysis above.

Theorem 3.6 (2): The maximum number of strongly connected

components of order 4 in a n -BT graph of order $n(n > 3)$ is

$$\binom{n}{4} - \frac{n}{2} \binom{\frac{n}{2}-1}{3} - \frac{n}{2} \binom{\frac{n}{2}-2}{3} \text{ if } n \text{ is even or } \binom{n}{4} - n \binom{\frac{n-3}{2}}{3} \text{ if } n \text{ is odd.}$$

Up to now, we may have already noticed that this conclusion maybe can be generalized, and we may also discover that the reason why Theorem 3.6 (2) still holds is that the construction is powerful enough—it even does not have to change even though the number of bad conditions increase. Therefore, we may assume that the key to generalize this theorem may lie in the graph itself. The following discussion will explore the property of this type of graphs and why it can seem to satisfy all the needs when finding the maximum number of strongly connected components.

3.4.3 n -BT and Strongly Connected Component of Any Order

For this part, we will first set the theorem following to be our goal. As the last two sections indicate, the generalization of the theorem should be as follows.

Theorem 3.6: The maximum number of strongly connected com-

ponents of order m in a n -BT graph of order $n(n \geq m > 2)$ is

$$\binom{n}{m} - \frac{n}{2} \binom{\frac{n}{2}-1}{m-1} - \frac{n}{2} \binom{\frac{n}{2}-2}{m-1} \text{ if } n \text{ is even or } \binom{n}{m} - n \binom{\frac{n-3}{2}}{m-1} \text{ if } n \text{ is odd.}$$

Proof: For this theorem, we will not start with the classification of bad conditions, because for a strongly connected component of order m ,

we have no idea how many conditions there will be except for two that must exist:

- A. There exists a vertex, whose arcs linking the other $m - 1$ vertices are all unidirectional and direct out from this vertex.
- B. There exists a vertex, whose arcs linking the other $m - 1$ vertices are all unidirectional and direct to this vertex.

We can still prove the upper limit similarly by counting the least number of $|\alpha|$ (necessity). Then, with the help of the graph, our goal is to prove it only contains bad conditions A or B, and that all the bad condition B will coincide with bad condition A so they do not need to be considered again (sufficiency). These two steps can help us complete the proof of the theorem.

Necessity: First, just as we have proved in the last section when $m = 4$, similarly we can repeat the process by dividing n into odd and even, proving each respectively. After calculating the sum of $d^+(v_i)$ where $i \in 1, 2, \dots, n$, we will still construct the function and this time the function constructed to support our theorem should be $f(x) = x(x-1)(x-2)\dots(x-m+2)$, which is a convex function when $x > m-2$. Similarly, we need to let $d^+(v_i)$ be as close as possible as their sum is already determined by the number of unidirectional arcs. According to the lemma, for $n = 2k + 1$, the equality of the value for all $d^+(v_i) = k - 1$ can be reached while for $n = 2k$, half of $d^+(v_i)$ should be $k - 1$ and another half be $k - 2$ in order for the number of bad condition A to be minimal. Therefore, the upper limit can be reached by plugging in the value of $d^+(v_i)$ and we can thus get that the maximum number of strongly connected components of order m cannot exceed

$$\binom{2k+1}{m} - (2k+1) \binom{k-1}{m-1} \text{ when } n = 2k+1 \text{ or}$$

$$\binom{2k}{m} - k \binom{k-1}{m-1} - k \binom{k-2}{m-1} \text{ when } n = 2k. (k > 2)$$

Therefore, the proof for the necessity condition of the maximum number is completed.

Sufficiency: For the construction of the graphs, both are the same as the constructions when $m = 3$.

However, we will approach these graphs in a different angle to prove only bad condition A needs to be taken into consideration.

Notice that we always place the n vertices equally spaced on a circle, and for each v_i , the vertices on the semicircle counterclockwise all have arcs directed from v_i . Suppose we randomly choose m vertices u_1, u_2, \dots, u_m on the circle counterclockwise and want to see if these vertices form a strongly connected component of order m . Consider the central angle included by arcs $u_1u_2, u_2u_3, \dots, u_mu_1$. The sum of these central angles should be 2π .

If none of these m central angles exceeds π (all of the m arcs are minor arcs), then there must be arcs directing from u_i to u_{i+1} (if $i = m$, then $u_{i+1} = u_1$) since u_{i+1} must be within the next $\left\lfloor \frac{n}{2} \right\rfloor$ vertices on the circle counting counterclockwise. Therefore, these m vertices must form a Hamiltonian cycle, so these m vertices must be a strongly connected component of order m .

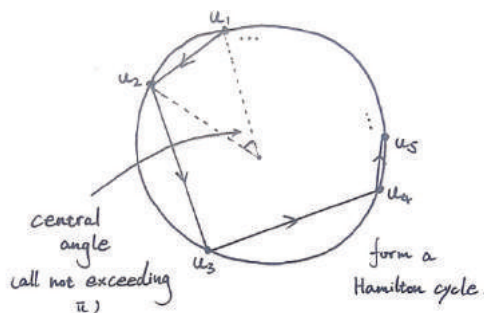


Figure 19.
Hamiltonian cycle formed by m vertices

If there exists a central angle that exceeds π , then there must be only just one angle that exceeds π because $m > 2$. Suppose this angle is included by arc u_iu_{i+1} (all except u_iu_{i+1} are minor arcs). If u_i and u_{i+1} are connected bidirectionally, then a Hamiltonian cycle also exists, and these m vertices must also be strongly connected. If they are not connected bidirectionally, then u_{i+1} should direct to u_i . Since the central angle included by arc u_iu_{i+1} exceeds π , then all these m vertices must be within a semicircle, and u_i and u_{i+1} are the two vertices that

are farthest away among these m vertices. Since the bidirectional arcs are all the diagonals that are the longest or the second longest, if the arc connecting u_i and u_{i+1} is not bidirectional, then for all the other arcs they also will not be bidirectional. For u_{i+1} , all the other vertices $u_{i+2}, u_{i+3}, \dots, u_m, u_1, \dots, u_{i-1}, u_i$ are all within the semicircle counterclockwise from u_{i+1} ; therefore, there must be $m-1$ unidirectional arcs directing from u_{i+1} to $u_{i+2}, u_{i+3}, \dots, u_m, u_1, \dots, u_{i-1}, u_i$, which satisfies the bad condition A. On the other hand, for u_i , all the other vertices $u_{i-1}, u_{i-2}, \dots, u_1, u_m, \dots, u_{i+2}, u_{i+1}$ are all within the semicircle clockwise from u_i ; therefore, there must be $m-1$ unidirectional arcs directing to $u_{i-1}, u_{i-2}, \dots, u_1, u_m, \dots, u_{i+2}, u_{i+1}$ from u_i , which means these m vertices also satisfy the bad condition B.

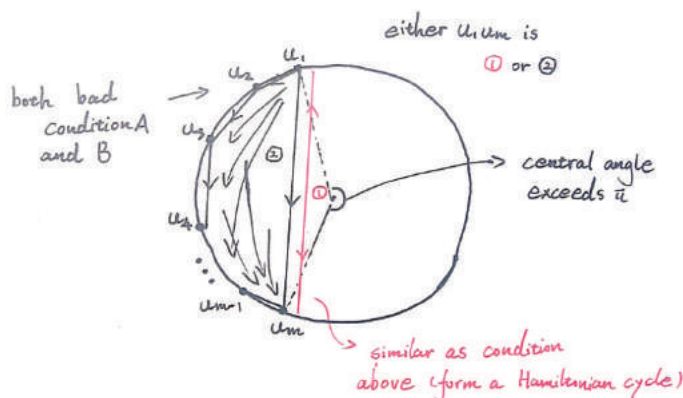


Figure 20.

Both bad condition **A** and **B** formed by m vertices

In addition, we should notice that it is the only case that bad condition can be generated in this construction, and the generated bad conditions satisfy both bad conditions A and B. Therefore, we only need to take into consideration the minimal number of bad conditions A to get the maximum number of strongly connected component of order m . Thus, the sufficiency of the theorem is completed.

Therefore, the proof of this theorem is completed.

The key to the proof above is that all the bidirectional arcs connected are the longest or second longest, so they are like the walls dividing the circle into two regions. If the vertices we choose to form the subgraph crosses the wall, then a Hamiltonian cycle is formed. If not, then bad condition A and

B will both be satisfied. That constitutes why this type of constructions is strong enough to hold maximum number of strongly connected components of any order.

Through this analysis we may understand why the constructions mentioned above are powerful. All the constructions we mentioned through whole section 3.4 may be taken as reference when considering the maximum number of strongly connected graphs.

4. Conclusion

This project especially focuses on the bidirectional graph and tournament, and proves several interesting theorems related to the bidirectional arc. With the discussion of Hamiltonian problems, Euler graphs and some basic properties and terms related to general directed graph and tournament in the first two sections as foundation, some proof in Section 3 can be thus simplified. As for the main part, Section 3 focuses on several problems and theorems related to the special transformation of bidirectional tournaments (BT), Hamiltonian theorems and strongly connected components (SCC).

The special transformation process can be applied when researching the graph's connectedness because the transformation will not affect the graph's connectedness while simplifying the bidirectional tournament. It helps one understand the core of the bidirectional graph and lays a solid foundation for later proofs. As for the Hamiltonian problem in the bidirectional tournament, the core theorem is Theorem 3.5, which gives the least number of Hamiltonian paths in a bidirectional tournament and its relationship with the maximum transformation time. This property about Hamiltonian paths is different from that in a simple tournament in which we can only prove there exists Hamiltonian paths. With bidirectional arcs added, the theorem can be thus strengthened. Lastly, section 3.4 explores SCC in a bidirectional tournament step by step, from specific to general, and proves the constructions with the maximum number of SCC. They also possess actual application value in real life, like how to arrange the one-way streets and two-way streets in order to maximize the connectedness of a city. The discovery and conclusion in this section on bidirectional tournaments can be actually extended to simple tournaments. The constructions in this section can also be applied to the research on strongly connected graphs and components as well as their interesting properties. Further research can be conducted in this field to further expand the theorem and this project may be viewed as a start or reference.

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The Impossibility of Certain Knowledge

A Critique of Rene Descartes' *Meditations on First Philosophy*

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Abstract

In this paper, objections against some of Rene Descartes' conclusions on the certainty of knowledge as found in his *Meditations on First Philosophy* will be presented. The paper is divided into three sections.

The objective of the first section will be to establish that despite his intention to call into question all assumed knowledge in order to derive certain knowledge, Rene Descartes does not question his assumption that "natural light" (commonly interpreted to refer to human reason) is a certain method of obtaining knowledge, even while using it throughout the *Meditations*.

The objective of the second section will be to cast doubt on the assumption described in the first section. This will be done via a method similar to that in the First Meditation, primarily by extending the Evil Demon thought experiment, as well as refuting the Cartesian Truth Rule through the idea of the Cartesian Circle. The goal is to establish that all beliefs are uncertain, i.e., fallibilism.

The objective of the third section will be to discuss the remaining options after the second section has established fallibilism. Two problems with fallibilism will also be discussed.

1. A Crucial Unstated Assumption in the *Meditations*

Rene Descartes declared that the purpose of the *Meditations* was to prove the existence of God and distinguish between the human body and the human soul¹, and to this end, he introduces Cartesian Doubt (though not by this name) in the First Meditation. In it, he asks us to assume that everything that can be called into even the slightest doubt should be assumed to be entirely false so that only certain knowledge remains². He then declares that there are too many objects in the world to doubt individually, so we should topple them all in one fell swoop by doubting our own senses³.

The problem lies in the fact that although there are beliefs about the mind that are not derived from sensory experience, but rather through observation of one's own mind, the doubt that is exercised in the *Meditations* is exclusively directed outside the mind, and not inwards. The First Meditation contains three exercises to detach oneself from one's faith in one's senses.

1. Our senses may deceive us in small ways such as distorting our perception of objects at a distance or near us.⁴
2. Even the most blatant perceptions via the senses may not be a true image of reality as evidenced by our inability to distinguish a dream from reality while we are dreaming.⁵
3. Although it may seem that all imagination, including a dream, is merely a combination of previously encountered experiences, it may very well be that a demon has deceived us, placing within our minds ideas of non-existent objects and making us believe that they actually exist.⁶

Descartes utilizes cognition to doubt his preconceived beliefs, but this naturally means that he does not doubt the veracity of cognition and the mind that performs it. Although the three exercises above have been used to guide one away from one's senses, at no point in the First Meditation does he cast doubt upon the mechanism he uses to cast doubt i.e. natural light.

Although Descartes casts doubt upon the senses through the Evil Demon thought experiment, his version of the thought experiment limits the demon's influence to our sensory perceptions and the beliefs we derive from our

1 AT VII 6

2 AT VII 12

3 AT VII 18

4 AT VII 18

5 AT VII 19

6 AT VII 22

senses⁷. To use the analogy of a computer, he makes the assumption that the demon has distorted only the input to the computer. In Descartes' thought experiment, the demon only damages the wire connecting the keyboard to the computer, and so the processor (the mind) filled the computer memory (our memory) with junk data (false beliefs) because the input is flawed, but not the processor itself. In the second section of this paper, the Evil Demon thought experiment will be extended to cast doubt upon cognition itself.

One might argue and suggest that Descartes' intention was to determine the degree that certainty can be achieved through natural light as he believed that it is the most reliable tool for certain knowledge that we have at our disposal. Thus, doubting it would merely lead to an intellectual dead end where certain knowledge could never be achieved. I argue that this amounts to assuming that the veracity of the apparatus by which we carry out our search is certain knowledge, then claiming to obtain supposedly certain knowledge. I further argue that it would be more valid to abandon the ideal of certain knowledge than do this, regardless of how fundamental the assumption is, because knowledge derived from an unverified assumption is by definition uncertain.

This paper intends to carry on the tradition presented by the *Meditations* by casting doubt upon a crucial assumption—that human cognition itself is capable of obtaining and verifying certain knowledge—that is not doubted in the *Meditations*. This will be done in order to investigate whether any certainty can survive this even more intense scrutiny.

2. Casting Doubt Upon Certainty

According to Descartes, intuition and deduction are the two valid sources of knowledge⁸. Descartes himself claims that Cogito is not a syllogistic inference, but rather a series of self-evident intuitions⁹, so let us examine intuition first. It must first be noted that the intuition is capable of making mistakes. The Monty Hall problem is a famous instance in which a belief instilled by intuition into some of the most learned of modern minds turned out to be categorically false but was not corrected until much later¹⁰, showing

7 AT VII 22, 23

8 *Cambridge Descartes Lexicon* 183, AT X 368, CSM I 14, cf. AT X 372, 400, 425; CSM I 16, 33, 48

9 AT VII 18

10 Zachary Crockett, "The Time Everyone 'Corrected' the World's Smartest Woman", *Priceonomics*, Aug 2, 2016, <https://priceonomics.com/the-time-everyone-corrected-the-worlds-smartest/>

that even the utmost intelligence and experience do not leave us infallible to errors of intuition.

The First Meditation dismantles certainty in the knowledge that that which we perceive by our senses exists, a certainty that seemed absolute and unquestionable by our intuition. There seemed to be no way to doubt it, until, that is, the first meditation showed the reader a way. Thus, it can be seen that a feeling of certainty alone is not enough to guarantee a piece of knowledge provided by the intuition, as Wittgenstein argued for.¹¹

A famous critique of Cogito, first introduced by Pierre Gassendi, is that presupposing the “I” in Cogito is begging the question, so the only certain observation can be “cognitive activity is occurring”.¹² Friedrich Nietzsche suggested that “It thinks” would be a more appropriate premise.¹³ However, what provides certainty to the fundamental intuition behind even these stronger versions of Cogito, “there is an occurrence of doubt cannot be doubted”? What makes it irrefutable? Just as we did not know how to refute the existence of what we sense, perhaps we simply do not know how to doubt the occurrence of doubt. In other words, what if our intuition is not inherently damaged, but we have not yet corrected it because we do not yet know how? This possibility alone refutes the absolute certainty of all of the above versions of Cogito.

Let us not stop there, however. As Descartes said of the senses, it is not prudent to place trust in that which has deceived us before⁹. In this case it is reason, so let us extend doubt over the reliability of natural light itself. Let us imagine that the Evil Demon did not limit itself to distorting what we could perceive through our senses or planting individual beliefs within us, but went further and directly damaged our intuition and deduction, such that our reason led us to believe any incorrect belief that the demon wanted us to believe.

How would this possibility affect the status of a belief one has obtained by reason? The first possible scenario is that the current belief has been obtained by sound reason (the demon did not interfere) and the second possible scenario is that the demon’s covert damaging of our reason led to the adoption of a false belief. To be sure that the first scenario is the case and the second scenario is not the case for something we believe, there would have to be a

11 Ludwig Wittgenstein, *On Certainty*, Basil Blackwell (ed.), 1969

12 Saul Fisher, “Pierre Gassendi”, *The Stanford Encyclopedia of Philosophy* (Spring 2014 Edition), Edward N. Zalta (ed.), <https://plato.stanford.edu/archives/spr2014/entries/gassendi/>

13 Jonas Monte “Sum, Ergo Cogito: Nietzsche Re-orders Decartes” (PDF), *aporia.byu.edu*, 2015, https://web.archive.org/web/20160804115732/http://aporia.byu.edu/pdfs/monte-Sum_ergo_cogito.pdf/

characteristic experience that distinguishes them—some symptom or landmark that shows that our belief is correct and not a deception by the evil demon. The issue is that such a landmark cannot exist, if the demon is capable of causing us to experience any illusion it wants. If it can, then even in the second scenario we could experience anything that we could in the first scenario, if the demon wanted us to.

We cannot say with certainty that the demon does not exist or is incapable of causing us to experience any illusion it wants either, because belief in any proof that the demon does not exist or cannot manipulate us in this way could be a false belief implanted in us by the demon. Thus, it seems that we cannot believe that the first scenario is ever certainly true and so any belief obtained by reason cannot be truly certain.

One objection to this may be that I am simply launching a barrage of appeals to ignorance. An appeal to ignorance¹⁴ often just demonstrates an infinitely small, but non-zero, possibility of something occurring, and thus has limited use in practical discussion. However, when considering the issue of certainty in the strictest, most fundamental sense, which is what this paper deals with, an appeal to ignorance achieves its purpose.

Descartes himself answers the question of certainty with the famous Cartesian Truth Rule: any “clear and distinct idea” must be certain knowledge.¹⁵ This is because a benevolent God would not allow us to be eternally deceived, and so would give us cognition that is reliable so long as we use it correctly¹⁶. This correct usage results in clear and distinct ideas, so by the grace of God, clear and distinct ideas are correct. Furthermore, this is similar to how he defines intuition, as “the conception of a clear and attentive mind, which is so easy and distinct that there can be no room for doubt . . . Alternatively, intuition is the indubitable conception of a clear and attentive mind which proceeds solely from the light of reason (rationis lux)”¹⁷.

The problem lies in that Descartes stated that proof of God’s existence is based on the existence of a clear and distinct idea of God that he has within himself¹⁸. In other words, proof of God’s existence is certain because of the Truth Rule. However, by the time he made this statement, he had not proven

14 Hans Hansen, “Fallacies”, *The Stanford Encyclopedia of Philosophy* (Summer 2020 Edition), Edward N. Zalta (ed.), <https://plato.stanford.edu/archives/sum2020/entries/fallacies/>

15 Lex Newman, “Descartes’ Epistemology”, *The Stanford Encyclopedia of Philosophy* (Spring 2019 Edition), Edward N. Zalta (ed.), <https://plato.stanford.edu/archives/spr2019/entries/descartes-epistemology/>

16 AT VII 54

17 *Cambridge Descartes Lexicon* 183, AT X 368, CSM I 14

18 AT VII 53

the Truth Rule, and had not proven that clear and distinct ideas are guaranteed to be true. Rather, the Truth Rule's validity is soon shown to depend on proof of God's existence, which is circular because proof of God's existence was already shown to rely on the validity of the Truth Rule. The Cartesian Circle, in short, is the idea that the Cartesian Truth Rule is logically circular and thus invalid.⁹⁵

Descartes attempts to counter the Cartesian Circle in the Objections and Replies by saying that God's existence is merely required for us to recall knowledge that we are not in the process of once again deducing¹⁹. In other words, natural light works regardless of God's existence, but it is God's existence that provides continuing certainty in our conclusions. Natural light can be used to obtain knowledge of God, and this proof provides certainty. The issue is that the Cartesian Circle still remains, because natural light has been shown to be not completely reliable by the extended Evil Demon thought experiment. Thus, God's existence as proven by natural light is uncertain, and so it cannot provide certainty of other knowledge.

This entire paper until this point has utilized intuition and deduction, including when doubting intuition and deduction. This seems to imply that the methodology used in this paper has been flawed from the start. To justify this, let us think about the job of a linguist. One field of study for linguists is identifying the boundaries and components of a language, oftentimes by using that very language. Is the language flawed? Probably. Natural language is inherently prone to ambiguity due to its highly uncontrolled evolution, so we can all agree that language is not completely perfect. This does not, however, lead us to automatically discard language the second a flaw within it has been revealed. In fact, language has been a necessity for communicating philosophical thought throughout history, despite its imperfections, just as reason has been a necessity for progressing philosophical thought.

It is justifiable to demonstrate via human intuition the lack of absolute certainty in knowledge that is derived from human intuition. Human intuition's inherent uncertainty naturally applies to this paper's analysis, as well, given that this paper uses it. However, when an uncertain tool can be used to demonstrate that it is itself uncertain, it is at the very least an interesting result, and one which may lead to a deeper comprehension and more effective application by we who consider it, such as in the case of language and linguistics. Reason may be uncertain, but it will continue to be utilized in this paper to see what results it gives us.

3. The Updated Status of Reason Under Fallibilism

Fallibilism seems to be the conclusion of Section #2. Things that we cannot intuitively accept may be correct, and things we are intuitively sure about may be incorrect. If a statement gives rise to a logical paradox, it may not be false because the Evil Demon shows that logic in general is not necessarily a purveyor of truth. We cannot be certain if some beliefs are more certain than others. We cannot even be sure if any of the mental processes that we perceive as occurring, including perception and reason, are happening. Naturally, this implies that the intuitions and inferences of Cogito, “I doubt”, “I think” and “I exist”, are uncertain and so Cogito does not provide certain knowledge. Intuition and deduction were used to show that they themselves are uncertain, even though they are how every conclusion in this paper has been made.

It may be the case that certain knowledge is impossible, but true certainty has never been present, and this does not seem to have worked out so badly for humanity. The scientific method, for instance, one of humanity’s greatest aids, has never claimed to provide truth, merely a greater chance of arriving at truth than without the scientific method. The continuity of causation in the natural world, no matter how likely it seems, has never been guaranteed, despite it being the basis of most of our practical beliefs.

The best we can do now is to find axiomatic beliefs, assumptions that we acknowledge are uncertain. Natural candidates are beliefs in the possibility of truth, the validity of reason, one’s existence, one’s capacity to think, one’s will, one’s capacity to act and the reliability of one’s senses. The possibility of truth and the validity of reason, for example, have been axiomatic since the start of this paper, which is how fallibilism was established in the first place.

Our reason tells us that uncertainty does not equal falsity or impossibility, or in other words, fallibilism is not skepticism. Thus, knowledge is not guaranteed to be false, just as it can never be certainly true, so the matter is not settled. So long as we continue to utilize reason, the best we can do is differentiate between certainty and reasonable belief. Abductive reasoning states that to the best of our knowledge (but not certainty), reason is worth using, the analysis of the implications of Section#2 is a goal worth striving for and it is possible to strive towards goals. Why should we believe the best of our knowledge? We have no certain reasons to, just as we have no certain reasons not to. However, now that fallibilism is in the picture, all we can do is add the clause “to the best of my knowledge” (implicitly or otherwise) to every statement we make and every belief we hold.

If we chose to do nothing unless we were certain, we’d be eternally paralyzed. For whatever reason, it seems that our wills desire to act, to not be

paralyzed and to conduct philosophical thought, so let us continue to use and obtain results from reason for the sake of philosophical exploration.

For the sake of readability, let us define and utilize the following symbols:

- S = the set of all statements
- U = the set of uncertain things
- C = the set of certain things
- F = the belief in fallibilism, which is the belief that all beliefs and statements are uncertain but may be possible. F can be expressed as believing that $S \subseteq U$.

The first problem this section shall deal with is, “If $C = \emptyset$ according to the Evil Demon thought experiment, then is it not paradoxical for the thought experiment to imply that $F \in C$?” Let us consider the two possibilities.

1. **$F \in C$** : It seems to be the case that the thought experiment does indeed paradoxically imply that $F \in C$. Let us produce a form of F that logically allows its own certainty: “The set of all statements except this statement $\subseteq U$.” However, the evil demon renders every statement claiming to be certain, including this above expression of F , as false.
2. **$F \in U$** : The issue of claiming F is perhaps more resolvable if we admit that even though we claim F , we do not claim that it is certain and that it is still the case that $F \in U$. In other words, F is true to the best of our knowledge. There is actually no logical paradox in claiming $F \in U$. $F \in C$ occurs when $S \subseteq U$ is considered to be certain. Instead of claiming F as certain, we could simply believe F while admitting that even $F \in U$, as the ancient Pyrrhonists did. This does not mean that $S \subseteq U$ is considered to be a certain statement, and so there is no paradox.

The second problem with F that this paper will deal with is the problem of the infinite series that arises from the second response above. If F is believed, the statement “ $F \in U$ ” should also be uncertain. “ $F \in U$ is uncertain” is also a statement, so there is uncertainty about the uncertainty of $F \in U$, and so similarly there is uncertainty of the uncertainty of the uncertainty of $F \in U$, and so on, infinitely.

Imagine that this infinite stack of uncertainty is like a Babushka doll with the statement “ $F \in U$ ” in the center. Let us number the subsequent layers.

- Layer #1: $F \in U$ is uncertain, so F is possibly certain.
- Layer #2: Layer #1 is uncertain, so $F \in U$ is possibly certain, so F is possibly uncertain.

- Layer #3: Layer #2 is uncertain, so layer #1 is possibly certain, so F is possibly certain.
- Layer #4: Layer #3 is uncertain, so layer #2 is possibly certain, so layer #1 is possibly uncertain, so $F \in U$ is possibly certain, so F is possibly uncertain.

What we find is that each new layer alternatively renders F possibly certain or possibly uncertain. What makes our work very easy from here is that possible certainty and possible uncertainty are simply two forms of uncertainty. So, every new layer, all the way to infinity, simply restates that F is uncertain.

In fact, this infinite uncertainty series still holds even if “ $F \in U$ ” is replaced with any other statement X. Note that is extremely similar to infinite regress and the “Problem of the Criterion” as conceived by the ancient skeptics, particularly Sextus Empiricus.²⁰

Let us further think of this infinite uncertainty series as though it is a mathematical series like Grandi’s series ($1 - 1 + 1 - 1 + 1 \dots$).²¹ What makes Grandi’s series such an appropriate analogy is that each term in the series negates the term before it, similar to how the uncertainty series leads to confusing results because each “term” casts doubt on the term before it. There is much depth that I will not get into here, but the fact that I wish to discuss is that the sum of the Grandi’s series can be taken to be the fairly intuitive value of 0, or the unintuitive values of 1, and $\frac{1}{2}$, as well, all three of which are backed up by some mathematical logic. The key part of this analogy is that there seems to be a consensus that, out of the three options, $\frac{1}{2}$ is the most rigorous value that can be assigned to Grandi’s series.²¹ Conveniently, possible certainty corresponds nicely to 1, possible uncertainty corresponds nicely to 0 and uncertainty corresponds nicely to the “average” value of $\frac{1}{2}$.

Human intuition is simply not well adapted to analyzing infinite series, so the uncertainty series very quickly registers as absurd. As Grandi’s series shows, however, infinite series need not be dead-ends. Infinite regress as originally conceived, for instance, has candidate solutions like coherentism.²⁰ In the case of the uncertainty series, knowledge is simply reaffirmed to not be a barren void where plants of belief cannot grow. Rather, it is shown to be a field in which all plants that grow were planted by us, and even if we cannot tell if they are plastic or not, they exist to the best of our knowledge. In other words, once again, fallibilism need not imply skepticism.

20 Kevin McCain, “The Problem of the Criterion”, *Internet Encyclopedia of Philosophy*, <https://iep.utm.edu/criterio/>

21 “Grandi’s Series: Divergent but Summable”, *ThatsMaths*, <https://thatsmaths.com/2018/07/12/grandis-series-divergent-but-summable/>

Even if uncertain, beliefs appear to be justifiable and pieces of knowledge appear to be capable of being assigned a probability of being true. This is partly because of the crucial uncertainty of statements like “Nothing can be justified”, “The set of all beliefs= \emptyset ” and “Thinking is not occurring.” Just as reason demonstrated F, so has reason demonstrated the possibility of correct beliefs. The only catch is that we can never be certain that they are correct.

Conclusion

This paper first established that Descartes’ *Meditations* assumes the veracity of reason in the first section and that all belief is uncertain via an extended version of Descartes’ Evil Demon thought experiment in the second section. This all led up to the key idea in the final section, perhaps the most absurd of the three sections: fallibilism renders even reason as uncertain.

The proposed conclusion was that although all belief is uncertain, belief need not be abandoned entirely. In fact, attempting to justify belief is all that remains in the face of fallibilism. The question is, “Which beliefs are justified?” This paper has used reason, and so it naturally claims belief in reason to be one. The only conditions are that the uncertainty of all belief is to be kept in mind and reason’s status is to be relegated to that of a tool that we use without certain reasons to. In short, the best of our knowledge is like a boat adrift in a sea with no land in sight. But as far as we can tell, it is still sailing.

Naturally, a paper of this length cannot adequately deal with all questions that arise, questions such as “Why take reason and truth to be axiomatic at all?” To say that it is because our wills demand it raises another question: what makes our wills desire truth and use reason? If our wills are uncertain, then why bother carrying out any action? Do we have the option to not use will or reason? Speaking of belief, is belief in belief a required axiom? What about belief in belief in belief? Should we settle by saying, “I believe in belief in belief in belief and so on until infinity”?

Furthermore, it is a *logical* requirement that a tool cannot be used to justify itself, and like all logical requirements, it is uncertain because, as it has been shown, logic is uncertain. This raises more questions still. Can reason be used to justify itself in spite of logic saying it cannot? Can the use of reason be justified without the use of reason? Speaking of questions, all of the questions and doubts that are being raised here, including those about reason, are arguably being raised by our reason, so can we really doubt reason? What are the implications of trying? Does the fact that these questions are raised because of reason matter?

If we are speaking of doubting reason, the abandonment of reason comes to mind. Given that reason has been used to justify F, do certain beliefs

return if reason is abandoned? If so, should reason be abandoned? Is there an alternative to reason? If reason is abandoned because of F, then does that mean that reason caused us to abandon reason? Does the abandoning of reason require reason and if it does, would it imply that reason cannot be abandoned? Are all of these questions self-defeating, given that they ask for reasons to reject reasons?

As fundamental and intriguing as these questions are, their answers may not actually be urgently required. Practically speaking, the lack of certain knowledge does not need to affect life. A major consideration that arises now that absolute certainty is out of the picture is, "Should we continue living at all if the value of everything that gives life value could be an illusion?" What I would first like to note is that continuing to live while being aware of life's uncertain value is arguably a choice, albeit one with the very natural, instinctive answer of continuing to live. To the best of our knowledge, the reader of this paper is living, despite hopefully being convinced that there is doubt about everything, including life's worth. Why is this?

Perhaps it is because death's value is also uncertain. Perhaps it is also because everything having a minimum amount of uncertainty does not necessarily imply that life is certainly worthless, because as stated before, uncertainty does not equal impossibility. Furthermore, we still perceive all that which gives life meaning, even if it may be an illusion. This illustrates the idea that even if all belief is uncertain, one has the option of living on just as one had before. The only difference is that now, one must believe and conduct one's mind and guide one's will despite knowing that no belief is certain, but only correct to the best of one's knowledge. But regardless, life can go on even in pure uncertainty.

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Would Limiting Animal Product Consumption Be an Effective Public Health Strategy?

The Role of Industrial Farming in the European Union as a Catalyst for Foodborne Disease Resulting from Antimicrobial-resistant Bacteria.

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Abstract

Although a significant amount of evidence linking animal-to-human spread of antimicrobial-resistant bacteria (ARB) to the increasingly heavy burden of antimicrobial resistance (AMR) on public health exists, there is a lack of research showing how the exact amount the use of antibiotics in farming or the dietary choices of an individual impact the risk of ARB-related infections. Considering the current burden of AMR on world health, the World Health Organisation has announced that without harmonized and immediate action on a global scale, the world is heading towards a post-antibiotic crisis in which common infections could once again kill (World Health Organization, 2016). The European Union (EU) has been described as a superpower due to its influence, giving its decisions regarding this issue much weight (McCormick, 2007). Hence, this study strives to analyse the extent to which the use of antibiotics in farming impacts human health and the role of dietary choices in ARB-infection risk whilst pointing out knowledge gaps where applicable to promote further research into this issue.

Due to a lack of large scale data found to answer the research questions, this project has as its outcome some proposed solutions to these important questions. This paper is intended to begin to answer the questions highlighted above and give incentive for further studies into the matter. Despite EU efforts, levels of AMR are increasing in the EU/EEA area, with a 0.7% increase in third-generation cephalosporin resistance and a 2% increase in human cases of Salmonellosis from 2014 (2013 for Salmonella) to 2017 (ECDC, 2018). Some problems stemmed from differences in MS policies, suggesting a need for fundamentally different approaches that could be done on the individual level. Vegans have a significantly lower ARG load in their gut microbiota according to a study using data from 26 vegans and 32 omnivores (p-value of 0.0119 when compared to vegetarians and omnivores but a p-value of 0.7416 when compared to vegetarians), suggesting that veganism might act as a significant public health strategy to limit ARB infection risk (Losasso et al., 2018).

Though the exact extent of the use of antimicrobials in agriculture for public health is yet to be measured, veganism as a personal and public policy choice offers a likely answer to the problem. To begin to evaluate the biggest sources of ARB-infections in public health settings, this study proposes asking patients to indicate any high-risk activities (in terms of contracting ARB infections) around the time of the infection along with existing data collection structures in order to inform policy makers of the biggest contributors to this issue and concentrate their efforts as such.

Abbreviations

AMR	antimicrobial resistance
ARB	antimicrobial-resistant bacteria
EU	the European Union
EU/EEA	The European Union (EU) and European Economic Area (EEA)
WHO	World Health Organisation
MS	Member State of the European Union
ARG	antibiotic resistant gene
E. coli	Escherichia coli
ECDC	the European Centre for Disease Prevention and Control
AP	Action Plan (of the European Union)

NAP	National Action Plan (of an European Union Member State)
EFSA	European Food Safety Authority
EMA	the European Medicines Agency
STEC	Shiga toxin-producing <i>Escherichia coli</i>
HUS	haemolytic uraemic syndrome
C. jejuni	<i>Campylobacter jejuni</i>
C. coli	<i>Campylobacter coli</i>
MRG	metal-resistance genes
EC	European Commission
EARS-Net	The European Antimicrobial Resistance Surveillance Network
NGO	non-governmental organization
QALY	quality-adjusted-life-year

1. Introduction

Antimicrobial Resistance has become a global health concern (Nhung et al., 2017). In the European Union (EU) alone, AMR is responsible for an estimated 33 000 deaths per year, costing 1.5 billion Euros in healthcare costs and lost productivity (Antoñanzas & Goossens, 2018). There is a substantial amount of evidence highlighting the contributions of animal-to-human spread of antimicrobial-resistant bacteria to the increasingly heavy burden of AMR on public and veterinary health (Marshall & Levy, 2011).

Though the emergence of AMR in pathogens is a natural occurrence, it is greatly affected by human action (Woolhouse, Ward, Bunnik, & Farrar, 2015). Unclean, warm and antimicrobial-rich environments like industrial European animal farms form a great incubator for the emergence of ARB (EFSA & ECDC, 2019). Excessive antimicrobial use in industrial farming stemming from the intensification of farming practices is a growing issue in most of the developing world (Boeckel et al., 2015). The use of excessive antimicrobials as a strategic tool rather than as a last resort therapeutic tool for preventing disease and promoting animal growth remains essential in most modern industrial farms. Though these measures are often economically reasonable when considering animal welfare, logistics and efficiency in large industrial farms, where personal administration of antibiotics might become very inefficient, it also contributes to a higher risk of mutations in the surrounding bacteria, leading to an increase in ARB (Knobler, 2003). Antibiotic-resistant bacteria maintain themselves in the gut microbiota of the animals until slaughter, where it comes to contaminate the carcass of the animal or the animal's byproducts (eggs, milk) if decontamination processes are inefficient or incomplete. From the farm, further food processing, shipment or storage might result in the growth or re-contamination of the animal

product, which, if failed to cook at an adequate temperature and duration, or if the food product becomes re-contaminated during the process, likely results in resistant bacterial colonization or infection after consumption. Depending on the type of infection caused and the consumer's access to proper medical care, the outcome of being infected by an antibiotic-resistant pathogen might be a longer treatment period due to the prescription of antibiotics the pathogen is resistant to, or the patient might die as a consequence of lacking treatment alternatives.

As another consequence to European intense farming practices, antimicrobial resistance has developed to every class of antibiotics introduced into hospitals as a consequence of regular and multipurpose use of antibiotics, dissemination of resistant bacteria via fecal contamination, and intensive animal production (Pal et al., 2017) (van den Bogaard & Stobberingh, 2000). Additionally, the discovery of fundamentally new classes of antibiotics has been very slow, worsening this issue (Pal et al., 2017).

The central issue of this paper is not whether antibiotic use in animals leads to humans experiencing foodborne diseases that become increasingly difficult to treat. What remains to be answered by the scientific community is: at what exact frequency foodborne disease resulting from antibiotic use in animals occurs and to what extent should resources be used to intervene (Knobler, 2003)? With a public health crisis as severe as AMR, limited resources should be diverted to the area that resolves the issue most effectively. This paper looks into AMR in the European Union through examples of *E. Coli*, *Salmonella* and *Campylobacter* to begin to show the extent of the link between the use of antimicrobials in farming and disease among the consumers of the food. Additionally, it will describe the extent and efficiency of the European Union in resolving this issue through different means to see whether AMR is a public health concern that could be effectively resolved with the help of this institution. Finally, the paper will question whether limiting animal product consumption as a public health strategy would effectively help resolve this issue, as limiting AMR in animal products could be speculated to be much more expensive and inefficient than just abstaining from them to promote overall public health. The promotion of veganism and vegetarianism in particular will be referred to as a possible method of limiting ARB infections on a wider scale. For the purposes of this paper, veganism will be defined as the practice of not eating any animal products and vegetarianism as the practice of not eating meat, but eating other animal products, such as cheese or eggs (Cambridge English Dictionary). This paper is intended to begin to answer the questions highlighted above and give incentive for further studies into the matter.

2. Short Literature Review

Antimicrobial Resistance (AMR) has only become a much talked about topic outside of the academic community over the last decade or so, due to its worsening effects on the social, economic and political conditions of the whole world. Correspondingly, most wider scope review articles have been written within the last 20 years, due to a lack of coherent data on the issue before this time frame. In fact, a lack of data and coherence continues to be a major issue to this day, as can be seen from the European Centre for Disease Prevention and Control report on the burden of AMR on the EU/EEA region (Cassino et al., 2018). Currently, reports of AMR bacteria in wildlife are particularly relevant and sought after due to a lack of evidence to link or de-link the spread of AMR from industrial farms to the rest of the surrounding environment (Marinho et al., 2016).

As has been explained above, a major component of research in this area comes from large-scale review articles and as a natural consequence of that, much of the literature used as primary references in this paper are large-scale review articles too. This would include an article examining a decade's worth of surveillance data from Portugal as one of the examples from Europe (Marinho et al., 2016) and a review article on AMR in bacterial poultry pathogens (Nhung et al., 2017). These large-scale review articles have been chosen for their ability to link collected large data sets to already existing research in a way needed to draw conclusions for this research paper with the goal of answering questions about public health, a very large-scale problem hard to generalize from smaller example sets. Additionally, to draw data for the public health policy aspect of this research paper, an evaluation of the previous 2011–2016 Action Plan has been used as a primary source (RAND Europe Uppsala University, & Directorate-General for Health and Food Safety (European Commission), 2015). As this article focuses on the EU, using evaluations of their current and previous work had to be a part of explaining their public health policies relating to AMR.

3. Common Antibiotics and Resistant Pathogens

Food-borne zoonotic diseases are a significant and widespread public health threat, with over 330 000 human cases reported in the EU each year, but the real number is likely to be higher (EFSA, 2018). Zoonotic diseases may spread through food but also through the surrounding environment of its production (Bueno et al., 2017). Food can become contaminated in many sections of the food chain, from production to packaging (Krause & Hendrick., 2011).

This paper will focus on resistant strains of *E. coli*, *Salmonella* and *Campylobacter* to begin to show the frequency at which they cause foodborne disease within the European Union. The resistance of these bacteria is a consequence of selection pressure placed on them by the high levels of antibiotic use that can be observed in most EU industrial farms (Knobler, 2003). The reasoning behind highlighting the use of *E. Coli*, *Salmonella* and *Campylobacter* in this paper as a way to show the role of industrial farming as a catalyst for ARB-related infections stems from their importance to human health. *Salmonella* and *Campylobacter* are the two most prevalent zoonotic diseases in the EU as of 2017, with *E. Coli* being used as a widespread indicator bacteria for these issues (EFSA, 2018) (EFSA & ECDC, 2019). *E. Coli* is a very widespread sub-type of bacteria, making for a great indicator species due to its prevalence in industrial farms and the speculated transfer of antimicrobial-resistant genes (ARG) that might happen between pathogens and bacteria in the environment (EFSA & ECDC, 2019).

Of all antimicrobial agents administered to food-producing animals in the EU/EEA region for 2016, tetracyclines, penicillins and sulfonamides accounted for 70% of the total sales (European Medicines Agency, 2018). Though the impact of resistance to tetracyclines, penicillins and sulfonamides does not represent the whole resistome of pathogenic bacteria that develop resistance to antimicrobial agents, examining the three that make up the majority of market sales acts as a significant starting point for showing the effect of AMR stemming from industrial farming on public health in the EU.

3.1 *Escherichia coli*.

Escherichia coli is a bacterium that is ubiquitous in the gastrointestinal tract of warm-blooded animals, and it is an extensively used indicator bacteria for monitoring AMR in animal husbandry (EFSA & ECDC, 2019). In 2017, the European Food Safety Authority (EFSA), the European Centre for Disease Prevention and Control (ECDC), and the the European Medicines Agency (EMA) released a joint scientific opinion arguing that the proportion of fully susceptible *E. coli* isolates could be used as an indicator for total antimicrobial use in the whole agricultural sector, with the assumption that only *E. coli* that is rarely exposed to antimicrobials will be fully susceptible (ECDC, EFSA & EMA, 2017).

Through mandatory monitoring of AMR in *E. coli* in all EU/EEA member states since 2014 in reference to food-producing animals and their food products, it can be seen that *Escherichia coli* resistance to major antibiotics is rising in almost all of the EU Member States (EFSA & ECDC 2019) (ECDC,

2017). A 2016 study using results gathered over a decade from more than 75 different sources in Portugal found that *E. coli* from food-producing animals has shown higher rates of resistance to tetracycline, streptomycin, trimethoprim-sulfamethoxazole and chloramphenicol (Nhung, Chansiri-pornchai & Carriquemmas, 2017). Notably, two of the three main groups of antimicrobials administered to livestock on an European scale are represented in that list—sulfonamides (trimethoprim-sulfamethoxazole) and tetracyclines, showing a link between antibiotic administration and corresponding ARG in food-producing animal microbiota (National Cancer Institute, retrieved in 2019). Additionally, a study using 22 *Escherichia coli* isolates from 13 different farms in Spain in 2012 found that all tested strains were multi-resistant to more than 3 antimicrobial families, with 50% being resistant to more than eight antimicrobials, among which resistance to tetracyclines and quinolones was the most prevalent (Solà-Ginés et al., 2015). These results are significant considering EFSA's, ECDC's and EMA's proposal; they show a dose of antimicrobials in the agricultural sector that is so high no *E. coli* samples were found to be susceptible to all antimicrobials, suggesting that across the board, in industrial farms, all bacteria are likely to develop resistance over time as a result of such high doses of antimicrobials in that region.

According to a facts page published by the ECDC, though *E. Coli* is a part of the normal bacterial flora of the gastrointestinal tract, some strains of the bacteria, namely Shiga toxin-producing *E. coli* (STEC), produce a toxin that could result in a serious infection (ECDC, 2017). Similarly to how the spread of ARB was outlined in the introduction, STEC may come to infect meat or other animal by-products in any part of the food production and consumption process if proper sanitation and cooking methods are not employed. The main reservoirs of STEC strains are grass-feeding animals, cattle in particular, whose faecal matter might contaminate their meat due to poor processing methods during slaughter, or their faeces might contaminate other foods (e.g. milk, vegetables) and water.

In fact, the use of antibiotics in individuals with STEC infections is not favoured because STEC bacteria respond to some antibiotics by producing excess Shiga-toxin, leading to an associated risk of developing “haemolytic uraemic syndrome” (HUS). The disease is characterized by acute kidney injury to acute kidney failure and an array of symptoms of the central nervous system (Freedman et al., 2016) (Obrig, 2010). HUS has a death rate of about 3–5%, with children and adolescents being most susceptible to the syndrome (Canpolat, 2015). The most common serotype of STEC is O157:H7, although non-O157 serotypes causing HUS do exist (Obrig, 2010). HUS has been classified by EFSA as a major public health concern due to recent

SPEC/HUS outbreaks in the EU and the severe symptoms associated with both diseases (ECDC, 2017). Additionally, the main form of treatment for SPEC or HUS is hydration, as antibiotics might worsen the disease, making it hard to treat in severe cases. Another concern surrounding the spread of STEC in relation to AMR is its ability to serve as a reservoir for different ARGs as a highly resistant bacteria (Srinivasan, 2007). The bacteria can disseminate ARGs through adopted horizontal gene transfer mechanisms. More details are given about the resistance mechanisms of *E. coli* in a paper written by Volz et al. in 2019.

From this data, it can be seen that resistance to *E. coli* is a serious problem within the European Union, even though some cases of *E. coli* infection do not need antimicrobial therapy (for example, HUS). Though the exact proportion of AMR *E. coli* infections of different forms that result from intensive farming is not known, it can be speculated that a large proportion of *E. coli* infections stemming from the community are food-borne. Regarding the suggestion of EFSA, EMA and ECDC, all *E. coli* that comes across with antibiotics, in this case, all *E. coli* in industrial farming units, would contract antimicrobial resistance and could come to infect humans if sanitation measures fail. Sadly, my research did not find a study linking antimicrobial resistance in food-producing animal testing isolates to the amount of reported *E. coli* infection cases, nor the amount of times sanitation measures fail. Therefore, as food-borne sources of AMR infections are widely accepted as a large source of the problem, *E. coli* infections resistant to antibiotic(s) are likely to be food-borne; the exact amount is yet to be quantified (Woolhouse, Ward, Bunnik & Farrar, 2015). More studies would be needed to find an exact answer to this issue.

3.2 Salmonellosis.

Salmonellosis, the disease resulting from *Salmonella* infection, was the second highest reported zoonotic disease in the European Union as of 2017 (EFSA, 2018; Merriam-Webster, 2019). Salmonellosis rates have stagnated following several years of decline in the European Union, mostly due to one MS beginning to report serotype data (EFSA, 2018) (Koutsoumanis, 2019). In 2017, Member States reported 91662 cases of Salmonellosis in humans, with *Salmonella* being the commonest detected agent to cause disease outbreaks. Though the EU has set reduction targets for *Salmonella*, 12 MSs did not meet at least one in 2017 (EFSA, 2018). Notably, EFSA reported that *Salmonella* rate results on pig carcasses and poultry from competent authorities tended to be generally higher compared to those of food business operators. Considering the widespread nature of *Salmonella* and a recent rise in it's

rates even though reduction targets have been employed, the resistance of *Salmonella* to antibiotic treatment in humans can be seen as a serious issue, as failure to treat the patient with antibiotics resulting from antibiotic resistance may cause death in patients with *Salmonella*. In 2017, 156 deaths from *Salmonellosis* were reported across 17 Member States. As not all Member States submitted data on people affected by *Salmonellosis*, the real number of *Salmonellosis*-associated deaths in the EU is likely to be higher than this.

The main sources of *Salmonella* in food include eggs, milk and meat products. Additionally, the aforementioned increase in *Salmonella* rates stemmed from animal products, as rates of the pathogen in vegetables and fruits did not significantly change. In *Salmonella* samples from humans, as well as from fattening pigs and calves of less than 1 year old, high proportions of isolates were found to be resistant to tetracyclines, ampicillin (a penicillin class antibiotic) and sulfonamides, whereas resistance to third-generation cephalosporins were uncommon, making the antibiotics a possible broad-spectrum treatment alternative (National Center for Biotechnology Information, retrieved in 2019) (EFSA & ECDC, 2019). Again, a link between the most common antibiotics administered to food-producing animals in the EU and resistance to the same antibiotics in both animal and human isolates can be seen. A total of 21.3%, or about 19524, of the confirmed cases of *Salmonellosis* in 2017 tested positive for resistance to at least one antimicrobial, which is up by 2% when compared to the rate reported from 2013 (EFSA & ECDC, 2015).

Antimicrobial resistance rates in *Salmonella* isolates obtained from carcase swabs of fattening pigs and calves, and caecal contents of fattening pigs and cattle, were about 20–60%, depending on the serovar (EFSA & ECDC, 2019). It should be noted that due to differences in MS' reporting, this data might not be an accurate approximate of AMR rates in *Salmonella* from pigs, calves and cattle in the EU. Though this may not be the case due to discarded animals, assuming that all food-producing animals fitting into those categories in the EU are used for later consumption and that the given antimicrobial resistance rate is correct, 20–60% of all eaten meat from fattening pigs, calves and cattle could contain AMR *Salmonella*. My research has not been able to find the rate of AMR from large-scale studies in poultry in Europe, nor any studies to show the rate at which people consumed ARB-infected food. However, considering only 13% of European consumers do not consume red meat and beef, the impact of 20–60% of that type of meat consumed on a frequent basis being infected with AMR pathogens is highly likely to result in an eventual infection if proper sanitation or cooking measures or cooking measures fail to be completed (Statista Research Department, 2016).

In a study using 44 samples collected over a seven year period in a hospital, ampicillin resistance was found in eight isolates and confirmed to be frequently associated with the presence of β -lactamases. Tem-like genes were most likely to be associated with ampicillin resistance. Of the 16 AMR isolates of *Salmonella*, eight were found to be resistant to tetracycline, with different tet genes associated with the resistance mechanism. TetA and tetB genes could be acquired in the intestinal tract by horizontal gene transfer from Enterobacteriaceae (Cabrera et al., 2004). Sulfonamide resistance in *Salmonella* has also been linked to certain ARG, namely sul1, sul2 and sul3. Class 1 integrons were found to always be associated with said sul genes (Antunes, Machado, Sousa & Peixe, 2005).

3.3 Campylobacteriosis.

Though the rates of campylobacteriosis are considerably underreported, the disease has been the most frequently reported cause of human food-borne zoonoses in the EU since 2004 (EFSA & ECDC, 2019). In 2014, more than 250000 cases of campylobacteriosis were reported, with *C. jejuni* and *C. coli* accounting for 99,7% of cases with specific species information. Symptoms of the disease can include abdominal pain, fever, bloody diarrhoea, headache and nausea. Antimicrobial treatments are usually not required for Campylobacteriosis, but effective treatment may shorten the duration of the illness. As such, the importance of AMR in Campylobacter-related infections stems from a large number of human infection cases and the fact that only some cases require antibiotic treatment—it is not always necessary to use antibiotics to treat this disease. As of 2017, the fatality rate of Campylobacteriosis was 0.04% (EFSA, 2018).

Using data from 19 MSs of the EU plus Iceland and Norway, *C. jejuni* and *C. coli* was found to have a high proportion of resistance towards ciprofloxacin (57,7%), a second generation fluoroquinolone, and tetracyclines (45,4%) in 2017 (EFSA & ECDC, 2019) (National Institutes of Health, U.S. Department of Health & Human Services, 2019). In Campylobacter, resistance to quinolones and fluoroquinolones has been reported to have a significant association with the threonine-to-isoleucine substitution at amino acid position 86 in the quinolone resistance-determining region (QRDR) of GyrA (Elhadidy et al., 2018). The tet(O) gene is responsible for tetracycline resistance in Campylobacter. Additionally, the persistence of *C. jejuni* through the controlled conditions of slaughterhouses might be due to different survival strategies than antimicrobial resistance. One such strategy for the bacteria is biofilm formation (García-Sánchez et al., 2019).

Strong-evidence food-borne campylobacteriosis outbreaks (n=33) have only been associated with meat and dairy product consumption, with milk (54.5%) and broiler meat (24.2%) accounting for the highest amount of reported incidences (EFSA & ECDC, 2019). Few MSs reported data on *Campylobacter* in food, making it hard to estimate the true amount of food-borne campylobacteriosis in humans. However, of the MSs that did report their findings, the highest amount of *Campylobacter* was observed in fresh boiler meat isolates (37,4% with 18 MSs reporting) and fresh turkey meat (31.5% with 10 MSs reporting). The amount of milk and cheese isolates containing *Campylobacter* was lower than 2%, with only three positive cheese samples, all from Slovakia.

Notably, a recent systematic review concluded that consumption of fluoroquinolones in animals was related to resistance to fluoroquinolones in *Campylobacter* spp. from humans in a significant way. Additionally, *C. Jejuni* accounts for 90.5% of *Campylobacter* infections in Europe based on data that provided species information. AMR in *C. Jejuni* and *C. coli* from humans in 2017 was 45.4% and 68.3% in tetracyclines and 57.7% and 63.5% in ciprofloxacin, respectively. Using that data from the two antibiotics that *Campylobacter* is most resistant to, 47.7% of *Campylobacter* infections are resistant to tetracycline and 58.1% are resistant to ciprofloxacin. Even though most *Campylobacter* cases do not need antibiotic treatment, with such a high rate of AMR in the two broadband antibiotics the pathogen is most resistant to, chances of complications are quite high.

4. Impact of Metal Resistance on AMR Through Co-Selection.

Antibiotics and antimicrobial metal compounds have many uses in agriculture, for example as feed additives, growth promoters or therapeutic compounds (Pal et al., 2017). Antimicrobial metal compounds, particularly ones containing copper and zinc, are used in agriculture and animal husbandry as growth promoters, fungicides, herbicides and antimicrobials. A few common metal compounds used in agriculture include but are not limited to copper compounds, e.g. basic cupric carbonate, cupric chloride and copper lysine sulfate, and zinc compounds e.g. zinc oxide, zinc sulfate monohydrate and zinc chelate (van den Bogaard & Stobberingh, 2000). A more detailed list of said metal compounds and their properties can be found in a paper published by Mourão, Novais, Machado, Peixe & Antunes in 2015.

Sometimes, antimicrobial resistance genes or ARGs are found together with mobile genetic elements that sometimes allow for antimicrobial resistance mechanisms to develop in metals in the surrounding environment.

Resistance that could develop as a result of the mechanisms outlined above would come to hinder the use of essential medicines outlined by the WHO, some of which include copper, zinc, cadmium and/or arsenic as active ingredients (World Health Organization, 2015). Additionally, metal-containing products are frequently used in clinical surgery (Pal et al., 2017). As such, the development of metal-resistance genes (MRGs) in antibiotics, or the development of ARGs in metals distributed in industrial farms, is a serious concern to consider, as the food produced in those farms may carry bacterium with ARGs and/or MRGs and come to impact human health through resistance to available treatment measures. Additionally, an emerging strain of copper-resistant *Salmonella* (enterica serotype 4,[5],12:i:-) has begun to circulate in Europe. With a high frequency of copper and silver tolerance, particularly among the two major *Salmonella* multi-drug resistant clones in Europe causing human infections, this strain might likely become more widespread as *Salmonella* accounts for the second highest amount of food-borne diseases in the EU (Mourão, Novais, Machado, Peixe & Antunes, 2015).

As examples, widely administered antimicrobial metal compounds containing Copper and Zinc are also added to animal feed in larger concentrations for achieving benefits beyond essential dietary needs in some countries (Rensing, Moodley, Cavaco & Mcdevitt, 2018). Copper may be prescribed in the EU for copper deficiency or as a fungicide to control foot-rot in cattle and sheep in concentrations that might select for resistance. In the EU, usage of Zinc additives for therapeutic uses has been allowed in some countries but this practice will be discontinued due to a 2016 report by the Committee for Veterinary Medicine Products at the European Medicines Agency, which recommended the withdrawal of market authorities for existing products and the refusal of new products due to environmental risks and chance of co-selection.

Many studies have reported significant positive correlations between the presence of ARGs and MRGs in various environments in and around industrial farms (Pal et al., 2017). However, correlation does not imply causation, and as AMR can rise from factors independent to MRGs in the surrounding environment, further testing would be needed to show the extent at which metal exposure influences the development of AMR in and around food-producing animals.

5. The Role of the European Union in Reducing AMR Rates

Resistant organisms are not constrained by state borders, so there is a need for action against AMR on both an international and an EU level. Though the European Union has targeted policy towards tackling AMR before the

European Commission (EC) Action Plan on AMR (2011–2016), this Action Plan (AP) was the latest that could be analysed due to completion, as the current set of APs will last until 2021 (RAND Europe, Uppsala University, & Directorate-General for Health and Food Safety (European Commission), 2016). This paper will mostly analyse past policies of the EU to understand the institution's efficiency in solving this issue, as current and planned policies can not be fully assessed before a significant part of the programme or the full duration of it has elapsed. Though the end of the next AP is in 2021, results from large-scale data collection for AMR in the EU have only been released until 2017 as of now, making it very difficult to analyse the current AP with data for just one year from EU summary reports.

The 2011 AP brought together interested parties in developing a coherent mode of action using relevant scientific opinions from EU risk assessment bodies, including ECDC, EFSA, EMA and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). The AP was designed to be holistic across both human and veterinary health aspects with the following areas in mind: monitoring and surveillance; appropriate use of antimicrobials; infection prevention; development of new antimicrobials, alternative treatments and diagnostic tools; improving understanding of AMR; and reinforcement and coordination of research efforts.

In 2015, the EC commissioned an independent evaluation of the 2011–2016 AP by RAND Europe that would consider 2011–2015 as the basis of meeting their goals. The evaluation used a mixed methods approach including online surveys, public consultation, interviews, workshops, desk research and eight case studies to assess whether the actions set out in the AP were the most appropriate ones to combat the issue, whether the objectives were still relevant in tackling AMR, and whether the ECs approach was holistic.

The evaluation found that the APs were successful in addressing the problems identified in 2011 in a near-holistic way (the role of the environment was not explored enough), but to varying extents. Most importantly, the AP was found to deliver added value in acting as a symbol of EU political commitment and thus stimulating actions from the EU to global levels. It was also successful in providing a framework to coordinate national action plans (NAP) on AMR, enabling more effective measures to be taken, especially in the areas of research and innovation. Examples include the Joint Programming Initiative on Antimicrobial Resistance and changes in the monitoring and surveillance of AMR, which could also be seen in the large-scale EFSA scientific articles used in this paper (e.g. EFSA, 2018 and EFSA & ECDC, 2019).

The report indicated that it would have been too early to identify impacts of the AP on antimicrobial consumption or resistance in humans or animals

by that point, however it did highlight some new laws bettering the issue. Using data from EFSA reporting on data collected from 2014–2017 available on EARS-net (a 2011–2015 AP initiative), the impacts of the AP can now be addressed in this field to some extent. The latest executive summary published in 2017 reports that despite the EU’s efforts, high levels of AMR remain in the EU/EEA for several bacteria-antimicrobial combinations (ECDC, 2018). In particular, lower resistance percentages were reported by northern-european countries when compared to southern-european MSs, and north-to-south and west-to-east gradients in AMR were evident in some species. For *E. coli*, combined resistance to several antimicrobial groups was frequent, with a small but significant 0.7% increase in third-generation cephalosporin resistance observed over the 2014–2017 period. In isolates from all reported human Salmonellosis cases in the EU, resistance to antibiotics increased by 2% between 2013 and 2017 (ECDC, 2018) (EFSA & ECDC, 2015). However, the number of reporting MSs has increased when compared to 2013. These results show that though the EU launched holistic efforts in tackling the issue of AMR for the continent, they were not impactful enough to stop increasing rates of AMR for *E. coli*, an indicator of the level of antimicrobial use and as such AMR for the whole EU, and *Salmonella*, one of two most reported food-borne disease pathogens. Bearing in mind the widespread nature of these ARB and their importance—discussed in previous sections—the European Union must likely consider different approaches to those used in the 2011 AP to effectively reduce AMR rates. A report from the European Public Health Alliance, a collection of NGOs working on public health in the EU, has released a statement saying that “the EU does have the competence to do much more than it has under the AMR Action Plan 2011–2016” (European Public Health Alliance, 2017) (European Public Health Alliance, 2019).

Additionally, the variability of Member States in terms of policy implementation were shown, with a special challenge being the areas related to human health, where the Member States are responsible for action and EU competencies are limited (RAND Europe et al., 2016). The AP is to a large extent coherent with the NAPs, as 61% of surveyed MS representatives indicated that their NAP and the AP have a similar scope, and 26% indicating the AP had a larger scope than their NAP. Overall, 84% of surveyed MS representatives and stakeholders agreed or strongly agreed that the AP identified actions best dealt with at EU level, showing a large amount of added value and impact. Current differences in MS policies also indicate that there is scope for significant reductions if best practices from better-performing MSs were applied (ECDC, 2018).

With limited data available on EU expenditure for activities outside of research, budget efficiency could not be assessed. However, expenditure

spent on research allowed for significant contributions to the AMR research funding landscape, but results themselves were too early to be addressed, as research and development take long periods of time.

The current AP or the EU One Health Action Plan against AMR was adopted on June 2017 and uses the recommendations made by the 2011 APs evaluation discussed above, feedback received on a European Commission Roadmap on AMR, and an open public consultation (Antoñanzas & Goossens, 2018). As expressed previously, it is not possible to currently evaluate the EU's effectiveness with the One Health program on a larger scale.

6. Conjectures, Knowledge Gaps, Suggested Research Investigations and Improvements

The role of the environment surrounding industrial farms in zoonotic disease infections is yet to be researched enough to make sound conclusions, however, most studies do report higher ARB concentrations by the source (the farm) with reducing concentrations downstream of the source (Bueno et al., 2017). Though antimicrobials use in animal farming is considered the greatest contributor to the presence of ARB in food, sewage from treated animals may impact vegetables grown on fertilized fields near the industrial farms, contributing to the spread of ARB infections through plant-based food sources. Still, animal-derived food consumption has been linked to accumulating ARGs within human gut microbiota with a much lesser tested ARG load in a group following a vegan diet (n=26) to a group following an omnivorous diet (n=32) (Losasso et al., 2018). The study used pairwise comparison adjusted results from 16S rDNA analysis with four ARGs (sul2, tetA, blaTEM and strB) quantified by qPCR. The study found that vegans had a p-value of 0.0119 when compared to both vegetarians and omnivores, whilst omnivores had a p-value of 0.7416 when compared to vegetarians. This suggests that the role of consuming animal products is likely the most important factor in infections caused by consuming ARB-infected food, with relatively low levels of ARG present in human gut microbiota for people abstaining from animal product consumption when compared to animal product consumers (including dairy).

That being said, the aforementioned paper has been the only paper to my knowledge to address this paper's topic, and it uses relatively small testing sizes to do so (n=26–32). Notably, other studies that cover this issue might have been published, but were not found during my research either because of the existence of a paywall or the possibility of inefficient research. To confirm or disprove this claim, further research must be conducted on this topic, with bigger testing sizes and more specific data on the participants'

eating habits to investigate the relationship between the consumption of animal products and ARBs in human gut microbiota. Additionally, though the presence of ARGs in human gut microbiota is one indicator for measuring the risk of infection from ARB, it does not show an undeniable link between the two, as the number of participants with infections stemming from ARB had not been measured along with the results of this study. Though these results do secondhand confirm the hypothesis that reducing consumption of animal products will lead to a lesser likelihood of ARB-stimulated infection as a consequence of a lower amount of ARB in the intestines, this difference is yet to be shown in a large scale study or review article. Additionally, a person might contract an antimicrobial-resistant infection as a result of many other factors not relating to the amount of ARG in their gut microbiota, making it very difficult to directly link animal product consumption with ARB induced infections in the participant, especially on a larger scale. It should be noted that this article will only focus on limiting the occurrence or treatment failure(s) of zoonotic diseases induced by the consumption of ARB. Considering this, it can still be speculated that reducing meat consumption will lead to a lesser chance of obtaining an infection from ARB.

Additionally, the European Union is yet to show any clear large-scale signs of reducing AMR rates in most major antibiotic strains according to my research, and the cost of these policies has not yet been assessed. Therefore, it can be speculated that the impact of the European Union as a food-producing animal industry reformer might not protect citizens of the EU from being infected by ARB-infections as well as abstaining from animal products could. As an additional strategy to fighting AMR through antibiotic restriction, the promotion of veganism or vegetarianism may decrease the chances of contracting ARB infections to the lowest they could be, considering most ARG stem from animal byproducts (see: common antibiotics and resistant pathogens). As a result of lower infection rates, the burden of AMR on public health systems in Europe would also likely decrease, from costing 1.5 billion every year to the EU in lost productivity and healthcare costs (Antoñanzas & Goossens, 2018). In the United States of America, a region-specific global health model was used to quantify the linked health and environmental consequences of dietary changes (Springmann, Godfray, Rayner & Scarborough, 2016). The study found that the economic benefits of switching to a more plant-based diet in the masses could account for 0.4–13% of global gross-domestic product by 2050. Using a different prediction model to assess Belgium, it was found that a soy-containing (vegetarian) diet could lead to 202 extra quality-adjusted-life-years (QALYs) and 107 QALYs per 1000 women and men respectively with societal savings of € 2 146 000 and € 1 653 000 (Schepers & Annemans, 2018). Not only could the promotion

of a plant-based diet help solve the issue of this paper, it is likely to reduce public health costs that could potentially then be funnelled into additional AMR research.

To be able to fully answer this research question, further research into the effects of ARG load in people with different diets, and the mechanisms behind obtaining ARB-infections, must be conducted, along with evaluations and cost analyses of the EU's current One Health AP. Importantly, studies looking into the empirical amount that antimicrobial use in food-producing animals impacts human health need to be conducted as well, to see the extent of the impact of industrial farming on this issue (Woolhouse et al., 2015). One way to do this could involve asking people infected by an antimicrobially resistant pathogen to indicate whether they have been involved with high-risk activities in terms of coming to contact with ARB before the diseases' onset. Those activities could, for example, involve eating raw meat from farms that have used antibiotics, not following proper sanitation procedures whilst working in an environment using high doses of antibiotics (industrial farms, hospitals) and other "high-risk" activities, which could then be compiled into data points according to activity and analysed to show the extent of industrial farming and/or other activities on public health. Further, this sort of data could be used to inform public policy decisions around reducing the effect of the highest risk activities if at all possible, to concentrate efforts where they are needed most.

7. Summary and Proposed Future Studies

This paper strives to review to what extent antibiotic use in European food-producing industrial farms impacts human health on an European scale, and review whether promoting veganism would work as an effective public health strategy to decrease the risk of obtaining an AMR infection among the population. Additionally, besides drawing new conclusions from published data, it points out knowledge gaps in this topic and proposes and suggests an improvement for some future studies.

About 330000 human cases of food-borne zoonotic diseases are reported in the EU each year (EFSA, 2018). Of those diseases, it could be speculated that their AMR rates are rapidly increasing, considering the recent proposal by the EFSA, EMA and ECDC to regard the AMR rates of *E. coli* as an indicator for total antimicrobial use in the whole agricultural sector (ECDC, EFSA & EMA, 2017). Though small-scale, a study from farms in Spain found all *E. coli* isolates that tested for AMR to be resistant to at least 3+ antimicrobial families. This suggested that in general, all bacteria are very highly likely to develop resistance over time because of antimicrobial doses that are so high

there are no completely susceptible *e. coli* present (Solà-Ginés et al., 2015). Again, these assumptions have been made using a small scale study and a relatively new proposal for an indicator due to a lack of data found during my research, pointing to a relatively high inaccuracy rate for this conclusion.

In the study, the specific AMR of two major pathogens, Salmonella and Campylobacter, were also outlined. For Salmonellosis, 21.3% of confirmed human disease cases were correlated with AMR Salmonella; from the agricultural side, 20–60% of obtained isolates from carcass swabs of fattening pigs and calves, and caecal contents of fattening pigs and cattle, were resistant to antimicrobials (EFSA, ECDC, 2019). Differences in MS' reporting were prevalent. Comparing those two percentages, it can be seen that the AMR of Salmonella impacting human health is likely significant. Only 13% of the EU does not consume red meat and beef, therefore 87% of Europeans are likely to consume meat with a 20–60% AMR rate on a somewhat frequent basis, increasing their chances of contracting AMR Salmonellosis via frequent contact (Statista Research Department, 2016). However, this assumes that the data collected from the MS' is close in value to the real rate considering differences in data collection, and that failures in correct sanitation methods, other ways of contamination, or the consumption of raw meat does occur at some times. Campylobacter infections are resistant to tetracycline at a rate of 47.4% and to ciprofloxacin at 58.1% (EFSA & ECDC, 2019). Campylobacteriosis is the most prevalent zoonotic food-borne disease with more than 250000 cases each year. Though the disease does not need antibiotic treatment at all times, chances of complications are quite high with such a high level of resistance in two major antibiotics. Using a small number of cases ($n=33$), all Campylobacteriosis outbreaks have been associated with meat and dairy consumption, with milk accounting for 54.5% and broiler meat for 24.2%. Few MSs reported data on Campylobacteriosis in foods, making it difficult to estimate the amount of food-borne resistant campylobacteriosis in humans. If this limited data is assumed to be correct, the outbreaks show a significant relation between food consumption (that is likely treated with antibiotics) and Campylobacteriosis with a high rate of AMR.

A 2017 executive summary reports that despite EU efforts, high levels of AMR remain in the EU/EEA (ECDC, 2018). A 0.7% increase in third-generation cephalosporin resistance and a 2% increase in human cases of Salmonellosis resistance were observed from 2014 to 2017 and from 2013 in the case of Salmonellosis. Though the EU launched holistic efforts to combat AMR through the 2011 Action Plan, with 84% of surveyed MS representatives and stakeholders agreeing that the AP identified the right actions to take at the EU level, it had not met its goals in reducing AMR rates (RAND Europe et al., 2016). Though the EU has tried holistic methods to solve the

problem of rising AMR rates in the union in the past, those measures failed in reducing rates of AMR with the previous AP. This suggests that the EU is likely to not succeed in meeting similar goals with the current One Health AP as a result of differing MS policies. Especially when it comes to human health, the EU has very little sovereignty, making it more difficult for measures against AMR to be fully coordinated.

As a proposed solution to add to current policies, the promotion of veganism on a large scale might significantly reduce the risk of AMR infection for humans following the diet. Though animal farming is considered the biggest contributor to the presence of ARB in food, sewage from treated animals may impact plants grown on fields near the industrial farms (Bueno et al., 2017). However, the only study I was able to find about the ARG load in people following different diets showed a very low rate of ARGs for vegans with a p-value of 0.0119 when compared to vegetarians and omnivores but a p-value of 0.7416 when compared to vegetarians, suggesting that the role of plant based food on the issue of food-borne AMR infections is quite small (Losasso et al., 2018). However, this study was conducted using a small testing sizes (26 vegans, 32 omnivores), suggesting that the finding might not mirror a larger population. Additionally, though ARG in gut microbiota are a good indicator for future risk in obtaining an AMR infection, it is not clear whether this would become the case in all participants. Furthermore, a person can come into contact with ARB in various other ways outside of their diet, and in the case of small testing sizes, those differences could not be disregarded. Still, as the only study found by my research addressing this topic, it will be assumed that veganism may act as a substantial way to decrease ARB infection risk on an individual level, thus acting as a good public health strategy. In addition, a study using a prediction model assessing Belgium found that vegetarianism may lead to extra societal savings of €2 146 000 and €1 653 000 over 1000 women and men, respectively (Schepers & Annemans, 2018). Therefore, as veganism can be speculated to be an effective public health strategy in lowering the risk of AMR infection in humans, it might also stimulate economic growth, making for a great public health strategy.

As for knowledge gaps, large-scale studies looking into the exact extent that antibiotic use on animals has on human health must be conducted. This paper also proposes that one way to address this link is to begin collecting data from zoonotic disease patients about whether they have engaged in high risk activities in terms of being in contact with ARB (e.g. eating raw meat from an industrial farm), with specific examples and options attached for clarity.

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Cockpit Instruments

A Historical Study of the Ergonomic Considerations in Aircraft

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Abstract

Due to aviation’s high-risk nature and the number of tasks that must be handled simultaneously, interactions between crew members and their aircraft are a key insurance of air safety.¹ Only if crew members interact with their machines properly and thereby make use of all available resources can the tasks of a cockpit be successfully handled and their airplane be flown safely.

At the center of these interactions lie the cockpit instruments: devices via which pilots continuously enter their commands and receive feedback. Cockpit instruments are the media via which information is circulated in cockpits. Therefore, the designs, which refer to the characters of individual instruments, and layouts, which refer to the ways in which various instruments are positioned relative to each other, of these instruments are the key determinants of whether pilots could effectively enter their commands into their aircraft and understand and interpret the feedback given by their aircraft.

1 Daniel Muñoz-Marrón, Francisco Gil, and Ana Lanero, “Are Crews Empowered with All the Resources Needed to Successfully Address an Inflight Emergency? Checklists, a Necessary but Insufficient Tool,” *Aviation* 22, no. 3 (November 13, 2018): 93–101, <https://doi.org/10.3846/aviation.2018.6254>.

This research is guided by the overarching evolution of cockpit instruments since the first human flight of the Wright Brothers. Specifically, this study examines how the designs and layouts of cockpit instruments have evolved over the past century, and attempts to explain potential factors behind these changes. In doing so, the ergonomic considerations of engineers from different times in history are analyzed using the instruments they designed to reflect a complete picture of the evolution of cockpit ergonomics, including but not limited to the concept of human-machine interactions, the concept of errors, and even the concept of automation in recent times.

1. Historical Framework

Research in the field of cockpit designs started before the First World War, with an initial focus on the characteristics of an “ideal pilot.”² Results of these studies soon prompted research on the selection and training of aviators during the Second World War. However, the majority of these early studies before the end of the Second World War focused exclusively on the context of the Air Force.³ Once the two World Wars ended, the context of research shifted radically from military aviation to an environment in which both military and civilian flights prevailed.⁴ The two World Wars witnessed significant changes in cockpit designs as planes were flying faster and higher, but initial research in this field tended to focus on either the pilot side or the machine side, with little attention being given to the coordination between the two bodies.⁵

The development of automated systems in the 1960s brought new challenges to cockpit crew members: they had not only to coordinate between themselves but also between humans and machines that were sometimes even more efficient in the executions of straightforward but essential tasks. As demonstrated by research at the NASA Ames Research Center, pilots at

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- 2 Daniel Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica, “FACTORES HUMANOS EN AVIACIÓN: CRM (CREW RESOURCE MANAGEMENT—GESTIÓN DE RECURSOS DE LA TRIPULACIÓN),” *Papeles Del Psicólogo—Psychologist Papers* 39, no. 3 (2018), <https://doi.org/10.23923/pap.psicol2018.2870>.
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 - 5 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica.

that time lacked these skills, and initial cockpits with autopilots could not deliver useful information to pilots in an efficient manner.⁶ A series of aircraft accidents in the 1970s, such as the collision between KLM Flight 4805 and Pan Am Flight 1736 in 1977 and the crash of United Airlines Flight 173 in 1978, also confirmed this point.⁷ In 1979, partly for this reason, NASA sponsored a meeting entitled Resource Management on the Flight Deck, an event during which the term Crew Resource Management (CRM) was adopted for the first time.⁸ During this meeting, NASA attributed most aircraft accidents to some or even many human factors, including failures in interpersonal communications, leadership management, etc.⁹ Also, the importance of effective cockpit designs was emphasized,¹⁰ as they lie at the core of the human-machine interaction system, ensuring that pilots can effectively enter their commands into their aircraft and continuously receive feedbacks from their aircraft. These results, together with testimonies from airline pilots at the time, provided the foundation for the subsequent, well-structured research and industry programs to develop more ergonomically efficient cockpits.

Starting in the 1980s, commercial airlines began to integrate CRM, including pilots' coordination with their cockpit systems, into their structured training programs. In 1981, United Airlines introduced the first CRM Training Program to its cockpit crews, and other airlines, such as KLM and Ansett, soon followed suit.¹¹ Since then, training programs in CRM have continued to spread to other airlines and military parties from all over the world.¹² Due to the omnipresence of human-machine interactions, the application of CRM was no longer limited to cockpit crews: other professions in aviation, such as aircraft manufacturing and maintenance, adopted CRM as a

6 Thomas P. Turner, *Cockpit Resource Management: The Private Pilot's Guide* (Tab Books, 1995).

7 Robert L. Helmreich, "Managing Human Error in Aviation," *Scientific American* 276, no. 5 (1997): 62–67.

8 Robert L. Helmreich, Ashleigh C. Merritt, and John A. Wilhelm, "The Evolution of Crew Resource Management Training in Commercial Aviation," *The International Journal of Aviation Psychology*, November 13, 2009, https://doi.org/10.1207/s15327108ijap0901_2.

9 Ibid.

10 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica, "FACTORES HUMANOS EN AVIACIÓN."

11 "ANSETT ALLOWS TIME FOR PROFIT RECOVERY," accessed September 16, 2020, <https://www.afr.com/companies/ansett-allows-time-for-profit-recovery-19950911-kaxk5>.

12 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica, "FACTORES HUMANOS EN AVIACIÓN."

core part of their employee training, and professions in other high-risk areas, such as surgery and underground mining, also initiated similar programs.¹³

From the evaluations by Helmreich and Marshall, we can identify the following six stages of CRM Training Programs since the 1981 initiation by United Airlines, each with their own characteristics and historical backgrounds on instrument designs and cockpit ergonomics.¹⁴

The first-generation programs involved seminars in which crew members analyzed their own flying styles, namely the fashions in which they coordinated with other crew members and their aircraft.¹⁵ Following United Airlines, other carriers soon developed similar programs to modify their crew members' flying styles that were deemed risky and not following strict procedures.¹⁶ Feedbacks to these first-generation programs were generally positive, although a number of pilots reported a sense of being "manipulated" by a group of scholars completely outside their field, such as psychologists.¹⁷ Some pilots even reported a loss of "professional dignity" as they now could not control their aircraft under their own will but instead had to follow the rules of machines.¹⁸

The second and third generations of CRM Trainings involved the practical integration of CRM knowledge into a broader and more complex context.¹⁹ In the late 1980s, simulators were used to provide pilots with the real-world experience of in-flight interpersonal communications.²⁰ Similar activities enabled pilots to better apply their conceptual knowledge to real cockpit settings, and also alleviated some pilots' sense of being "manipulated" by irrelevant scholars. Even more importantly, the feasibilities of existing cockpit designs were tested in simulators, as surveyed pilots reported very different opinions about the ergonomic designs of different simulators they flew.²¹

13 Robert L Helmreich, "Building Safety on the Three Cultures of Aviation," 1999, 6.

14 Helmreich, Merritt, and Wilhelm, "The Evolution of Crew Resource Management Training in Commercial Aviation."

15 Ibid.

16 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica, "FACTORES HUMANOS EN AVIACIÓN."

17 Helmreich, "Managing Human Error in Aviation."

18 David A. Mindell, *Digital Apollo: Human and Machine in Spaceflight* (MIT Press, 2011).

19 Eduardo Salas and Janis A. Cannon-Bowers, "The Science of Training: A Decade of Progress," *Annual Review of Psychology* 52, no. 1 (February 2001): 471–99, <https://doi.org/10.1146/annurev.psych.52.1.471>.

20 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica, "FACTORES HUMANOS EN AVIACIÓN."

21 Steven Morrison and Clifford Winston, *The Evolution of the Airline Industry* (Brookings Institution Press, 2010).

Impressed by the results of CRM Trainings, in the 1990s different authorities in aviation such as the Federal Aviation Administration and the UK Civil Aviation Authority began to make CRM Trainings a mandatory requirement for flight operators such as commercial airlines and the Air Force, a process which characterized the fourth generation of CRM Trainings.²² In this stage, the FAA initiated its Advanced Qualification Program for pilots, which was one of the biggest changes to pilot trainings in history. It emphasized the significance of CRM Trainings and allowed different airlines to devise their own CRM programs according to their individual situations, a step which made CRM Trainings much more flexible and effective.²³ Airlines even had the option to choose their own cockpit designs: faced with great competition from each other and pressure from airlines, Boeing and Airbus made the installation of certain cockpit features, such as touchpads and keyboards, optional.²⁴ In this way, airlines could adjust their own CRM Trainings based on the instruments they chose in their cockpits.

Starting in the mid and late 1990s, more and more parties started to regard CRM as “a strategy of error management and reduction” rather than error prevention.²⁵ The categorization of errors enabled flight operators to appreciate the unavoidable nature of errors in the cockpit setting, and aircraft manufacturers responded to this realization with new designs such as switch protections that reduced the chances of errors, a process that characterized the fifth stage of CRM Trainings.²⁶ Entering the 21st century, external threats were also added to CRM Trainings and cockpit design schemes to better the pilots’ situation awareness during flight, further improving aviation safety at large.²⁷ As cockpit ergonomics and CRM Trainings continue to evolve, they make our air travel ever safer, faster, and more efficient.

22 Rhona H. Flin, Margaret Crichton, and Paul O’Connor, *Safety at the Sharp End: A Guide to Non-Technical Skills*, accessed September 16, 2020.

23 Richard A. Birnbach and Thomas M. Longridge, “THE REGULATORY PERSPECTIVE,” *COCKPIT RESOURCE MANAGEMENT*, 1993, <https://trid.trb.org/view/571747>.

24 “Airbus A300 the Beginnings of Airbus—Modern Airliners,” accessed September 16, 2020, <https://modernairliners.com/airbus-a300/>.

25 Helmreich, “Managing Human Error in Aviation.”

26 Eduardo Salas et al., “Team Training in the Skies: Does Crew Resource Management (CRM) Training Work?,” *Human Factors: The Journal of the Human Factors and Ergonomics Society* 43, no. 4 (December 2001): 641–74, <https://doi.org/10.1518/001872001775870386>.

27 Daniel E. Mauriño, “CREW RESOURCE MANAGEMENT: A TIME FOR REFLECTION. IN: HANDBOOK OF AVIATION HUMAN FACTORS,” 1999, /paper/CREW-RESOURCE-MANAGEMENT%3A-A-TIME-FOR-REFLECTION.-OF-Mauri%C3%B1o/8ed4647f68337b05700d53bdd4b57275613c45f7.

2. Cockpit Ergonomics Before CRM Programs

Aircraft cockpits, particularly the instruments inside them, are the media via which pilots interact with machines. Pilots input their commands by rotating and moving various switches, yokes, and sticks in their cockpits and continuously receive feedbacks via various dials, displays, and even certain indicators, such as vibrations of their yokes. Thus, the evolution of the designs and layouts of these cockpit instruments essentially reflects the ways in which pilots interact with their machines. This results in an ongoing back-and-forth dynamic between human pilots and their tools, similar to the evolutionary dynamics between human interactions and their languages. In the following paragraphs, I am going to dive into the designs of different cockpit instruments in history and analyze the ergonomic considerations as reflected in these instruments.

When the original biplane of the Wright Brothers flew in 1903, it had a stopwatch (an instrument for measuring the length of flight time),²⁸ a tachometer (an instrument for measuring the working speed of the engines),²⁹ and an anemometer (an instrument for measuring the wind speed, which could be approximated to be the aircraft's flying speed).³⁰ None of these instruments was used to provide the pilot with information about external conditions; all of them were indicators of the plane's internal flight status.³¹ This was mainly due to the expectations for flight of this time: the biplane was not expected to fly above 20 meters,³² so the pilots' eyes served as the most important measuring device, and more instruments were not needed. As more planes with higher speeds and altitudes were designed in the First World War, aircraft manufacturers began to incorporate more flight instruments, such as compasses, engine revolution counters, altimeters, and air speed indicators, into cockpits.³³ By the end of the War, the typical number of instruments in a cockpit had reached two digits, as shown the De Havilland

28 Wolfgang Radner et al., "The Accuracy of Reading Speed Measurement by Stopwatch versus Measurement with an Automated Computer Program (Rad-Rd®)," *Acta Ophthalmologica* 95,no.2(2017):211– 16,[https:// doi.org/10.1111/aos.13201](https://doi.org/10.1111/aos.13201).

29 "Tachometer Measurement Device," *Encyclopedia Britannica*, accessed September 16, 2020, <https://www.britannica.com/technology/tachometer>.

30 E. J. Lovesey, "The Instrument Explosion— a Study of Aircraft Cockpit Instruments," *Applied Ergonomics* 8, no. 1 (March 1, 1977): 23–30, [https://doi.org/10.1016/0003-6870\(77\)90113-2](https://doi.org/10.1016/0003-6870(77)90113-2).

31 Ibid.

32 John Robert McMahon, *The Wright Brothers: Fathers of Flight* (Little, Brown, 1930).

33 Lovesey, "The Instrument Explosion— a Study of Aircraft Cockpit Instruments."

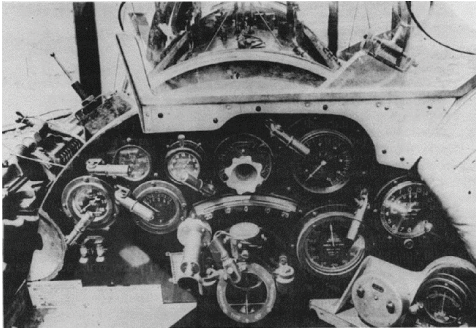


Figure 1.
The De Havilland 91 Bomber

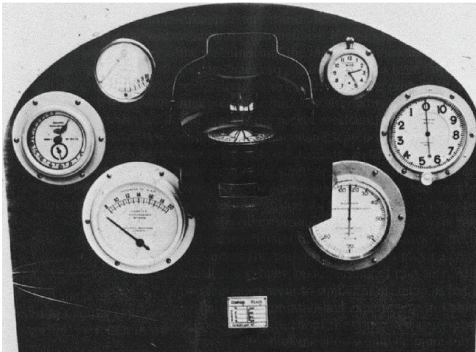


Figure 2.
*Early Cockpits with Clear
Graduation Markings*

9A Bomber cockpit in Figure 1.³⁴ These cockpit designs reflect the engineers' perceptions of cockpit ergonomics and their respective solutions to these considerations during this period. Due to the absence of pressurized cabin technologies, the maximum altitude of aircraft during this stage was about 20,000 feet.³⁵ Since this is still within the troposphere where weather effects occur, turbulence significantly affected flights. Thus, engineers at that time undertook great efforts to design instruments such that they could be seen clearly by pilots even under strong vibrations.³⁶ In Figure 2,³⁷ for example, the dials from a World War I Fighter were numbered in multiples of 1 or 10 and then subdivided into 10 intervals. While reading from these dials, the pilots' eyes could first focus on the large intervals and then read out the exact numbers. Even if the pilot could not detect precisely which smaller interval the

pointer was in, he/she could still have an approximate idea of the plane's status by looking at which larger interval the pointer was in.

The cockpit designs did not take into account the effects of fog, which would also occur at low altitudes.³⁸ At this time, pilots relied on major landmarks

³⁴ Ibid.

³⁵ S. Nazarali et al., "Cabin Pressure Aboard Commercial Aircraft and Non-Arteritic Ischemic Optic Neuropathy," *Acta Ophthalmologica* 95, no. S259 (2017), <https://doi.org/10.1111/j.1755-3768.2017.0T038>.

³⁶ Lovesey, "The Instrument Explosion—a Study of Aircraft Cockpit Instruments."

³⁷ Ibid.

³⁸ Mehmet Burak Senol, "Anthropometric Evaluation of Cockpit Designs," *International Journal of Occupational Safety and Ergonomics* 22, no. 2 (April 2, 2016): 246–56, <https://doi.org/10.1080/10803548.2015.1126456>.

for navigation,³⁹ and a strong fog could render these landmarks unidentifiable. Thus, even if cockpit instruments were designed such that they could be seen clearly when visibility inside the cockpit was low, the fog outside the airplane would make navigation extremely difficult, thus causing the flight to be cancelled. Therefore, fog was not a weather that affected cockpit ergonomic designs much during that time.

Counterintuitively, the advent of the jet age did not, per se, dramatically change the cockpit designs. As can be seen in Figure 3,⁴⁰ the Vampire jet airplane's cockpit differed little from previous ones: a number of dials remained mainly centered on the central panel. What truly changed the cockpit design was the new avionic systems, which were mainly used for communications, navigations, and autopilot flying. The night-fighter cockpit in Figure 4,⁴¹ for example, was the beginning of a rapid transformation. While the “basic six” blind-flying instruments—airspeed indicator, attitude indicator, altimeter, turn coordinator, heading indicator, and vertical speed indicator⁴²—were still placed in front of the pilot on a central panel (center left), in more modern systems, such as the Cathode Ray Tube (CRT), screens and contact breakers were also incorporated into other areas of the cockpit (upper right).

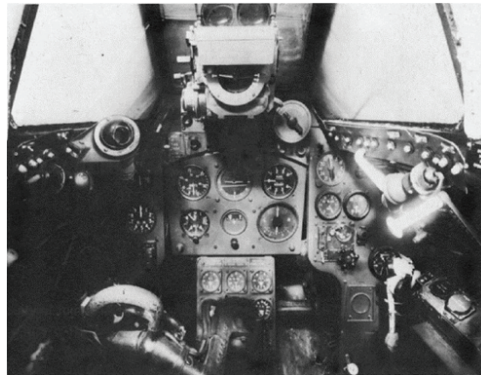


Figure 3.
The Vampire Jet's Cockpit

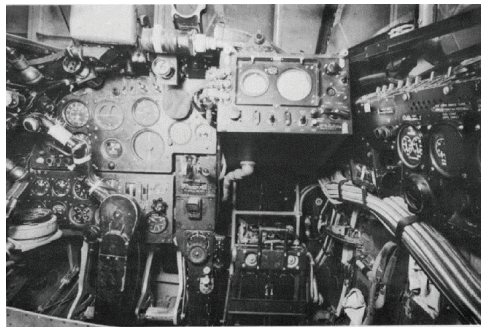


Figure 4.
The Cockpit of a Night-fighter

39 Ruwantissa Abeyratne, *Air Navigation Law* (Springer Science & Business Media, 2012).

40 Lovesey, “The Instrument Explosion—a Study of Aircraft Cockpit Instruments.”

41 Ibid.

42 “The Six Pack: Aircraft Instruments Explained,” accessed September 16, 2020, <https://www.mcico.com/resources/flight-instruments/six-pack-aircraft-instruments-explained>.

One new feature from this time with a particular impact on cockpit ergonomics was the advent of the CRT screens, which later became the foundation of the so-called “glass cockpits.”⁴³ Displaying information via traditional analogue dials with the same level of clarity could take much more space than displaying information via digital displays. A suitable analogy in our lifetime is the difference between a circular wall clock that lists all possible times and a digital timer that only displays a certain time. While the latter only uses the space to display one time, the former needs to use a full circle to indicate all possible times, although only one reading is needed. Similarly, even though the analogue cockpit dials used large spaces to display more information, namely all the possible read-outs, only one result was needed in most cases.

While the “outputs” of information were changing in form, the “inputs” of information were also evolving. For example, to change the status of a system a pilot initially needed to use his/her hand to rotate the switch to its intended position directly.⁴⁴ However, since it was very likely that pilots would touch these switches by accident and trigger unintended system actions, engineers adopted a different design: a pilot would now have to pull out the switch physically before rotating it to its intended position and pushing it back.⁴⁵ Accidental pulling is very rare in normal cockpit situations, so the chances of misinputs through incidental switch triggers have significantly decreased ever since. Similar strategies were also adopted in other devices beside the switches. For instance, the ground steering wheels of airplanes would be locked once the airplanes took off,⁴⁶ preventing the accidental movements of the steering wheels and the subsequent stresses upon the rudders.

As shown in Figure 5,⁴⁷ another change that accompanied this instrument evolution was the maximum speed of aircraft.⁴⁸ In fact, such an increase in speed played a large role in eliminating the redundant instruments in cockpits. As aircraft were flying faster and thus needed more systems to monitor

43 Jim Mitchell and Leopold P Vermeulen, “Flying Glass: A Qualitative Analysis of Pilot Perceptions of Automated Flight-Decks After 20 Years,” n.d., 16.

44 28 February 2006, “Cockpit Switch Set to Delay Airbus A350 Three Years behind Boeing 787,” Flight Global, accessed September 16, 2020, <https://www.flightglobal.com/cockpit-switch-set-to-delay-airbus-a350-three-years-behind-boeing-787/65998.article>.

45 “Cockpit Switches,” Aviation Today, January 1, 2012, <https://www.aviationtoday.com/2012/01/01/cockpit-switches/>.

46 “Advances in Aircraft Landing Gear,” accessed September 16, 2020, <https://www.sae.org/publications/books/content/pt-169/>.

47 Lovesey, “The Instrument Explosion—a Study of Aircraft Cockpit Instruments.”

48 Ibid.

their status, pilots not only had to make more decisions for all these systems but also had to make these decisions in less time. If the volume of information presented to a pilot kept increasing with the sophistication of these systems, the workload of a single pilot would eventually exceed his/her physiological limit and create safety issues.

3. Cockpit Ergonomics During CRM Programs

As machines evolved, attention was also given to the human aspects.

Accidents in the 1970s that were traced back to human errors, such as Eastern Airline 401 and Comair 444, prompted researchers and industry engineers to investigate the flying-styles of pilots, namely their fashions of controlling aircraft.⁴⁹ A meeting by NASA in 1973, in which pilots' conceptions of their cockpits and their problems' potential solutions were discussed,⁵⁰ together with a simulation study by the Ames' Research Center, revealed that the vast majority of pilots, both commercial and military, felt that their workload had grown too high.⁵¹ One pilot indicated that he had trouble with communication systems even during the cruising phase—usually the most peaceful component of a flight.⁵²

Another revelation was that the aviation industry, which was known for its strict procedures, was not as standardized as many people thought.⁵³ Crew members at that time, lacking the required training, often had personal preferences when flying. For example, some pilots preferred the “slam dunk approach” technique, in which they did not lower their airplanes until they were very close to airports.⁵⁴ This strategy was somewhat risky,

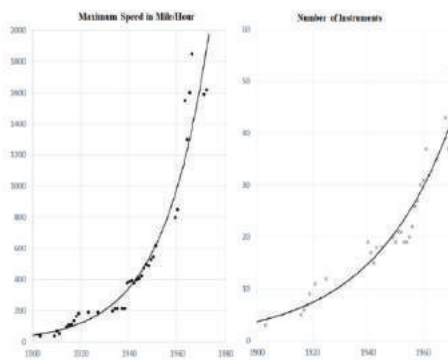


Figure 5.

The relationship between Time and the Maximum Flight Speed of Airplanes and the Maximum Number of Instructions in Cockpits

49 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica, “FACTORES HUMANOS EN AVIACIÓN.”

50 Mauriño, “CREW RESOURCE MANAGEMENT.”

51 H. P. Ruffe II Smith, *A Simulator Study of the Interaction of Pilot Workload with Errors, Vigilance, and Decisions* (NASA, 1979).

52 Ibid.

53 Ibid.

54 Jeb Burnside, “Briefing The Slam-Dunk Approach,” *Aviation Safety* (blog), June 17, 2009, <https://www.aviationsafetymagazine.com/features/briefing-the-slam-dunk-approach/>.

as it required the pilots to have exceptional time management; however, this method did save time, as not lowering the planes until the last minute significantly reduced the time for which the pilots needed to queue before landings.⁵⁵ Practices such as the slam dunk landing were prevalent in almost every aspect of the aviation industry; even procedures such as performing the checklists could be shortened or even skipped.⁵⁶

In light of these irregularities, NASA held a meeting in 1979 to discuss the manners in which pilots should behave in their cockpits. It was during this meeting that the term “Crew Resource Management” (CRM) was officially coined.⁵⁷ Airlines soon initiated training programs to develop pilots’ CRM skills; United Airlines initiated the first systematic CRM Training Program in 1981.⁵⁸ Although these discussions during the 1970s and early 1980s were chiefly about human aspects, they also emphasized the human-machine interactions intrinsic to the cockpit setting and further stimulated the use of cockpit CRT displays, as demonstrated below.

These multi-functional CRT displays, first seen to be used in the Vampire Jet, served to alleviate the pilots’ workloads in cockpits and enhance their coordination with automated systems. The logic behind this was that the new, larger screens would reduce the sense of “crowdedness” previously created by the large number of dials and switches. The Airbus A300, shown in Figure 6⁵⁹, which took her first flight in 1972, was the first commercial airplane to replace the central panel of dials with a Primary Flight Display.⁶⁰ Note that the use of CRT displays did not increase the amount of useful information presented to pilots: it conveyed the same amount of, or even less, information to the pilots in a way that was less physically tiring and more efficient. Aided by a multi-functional CRT display, the pilot would probably always be given basic flight information, such as altitude, airspeed, heading, and attitude.⁶¹ He/she would also have the opportunity to select other flight parameters, such as engine performance and balance data, while messages

55 Ibid.

56 Smith, *A Simulator Study of the Interaction of Pilot Workload with Errors, Vigilance, and Decisions*.

57 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica, “FACTORES HUMANOS EN AVIACIÓN.”

58 Muñoz-Marrón and Piloto del Ejército del Aire (Ministerio de Defensa). Psicólogo Especialista en Psicología Clínica.

59 “Airbus A300 the Beginnings of Airbus—Modern Airliners.”

60 Ian Moir, Allan Seabridge, and Malcolm Jukes, *Civil Avionics Systems* (John Wiley & Sons, 2013).

61 Lovesey, “The Instrument Explosion—a Study of Aircraft Cockpit Instruments.”

of system malfunctions could be presented to him/her in the form of warning lights.⁶² Before these CRT displays were widely utilized, crew members usually had to carry bags of manuals for radio frequencies, checklists, and emergency procedures to their airplanes, which presented stowage problems in the cockpits.⁶³ By contrast, high-resolution and large CRT displays offered an elegant solution to this problem. Figure 7 shows a typical pre-flight checklist on the PFD.⁶⁴ Note that the display was designed in such a way that the crew member had to interact with it as he/she was going through the checklist; only in this way could it be assured that the pilot did actually perform the items on the checklist. A dot would appear before an item once the crew member had finished checking that item. If the crew member was satisfied with the item, he/she would press the corresponding button(s) and continue to the next step.⁶⁵ If he/she missed a particular step, the system would warn him/her of the omission.

Even as electronic displays replaced much of the traditional dials, for some back-up instruments, mechanical dials were still used for their exceptional reliabilities and zero electricity consumption (they could work even when the plane was out of fuel and thus had no electricity).⁶⁶ A number of



Figure 6.
The A300 Cockpit, with a Primary Flight Display in front of each pilot

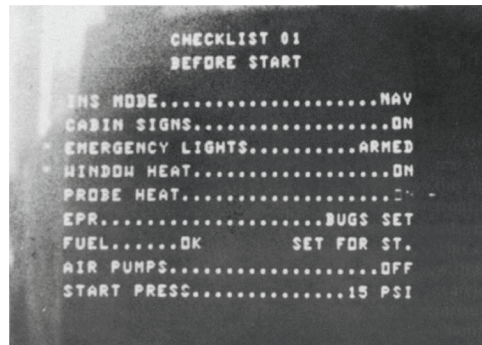


Figure 7.
A typical pre-flight checklist on the Primary Flight Display

⁶² George Emery Cooper, "A Survey of the Status of and Philosophies Relating to Cockpit Warning Systems," 1977, <https://doi.org/10.13140/RG.2.2.31249.02401>.

⁶³ Lovesey, "The Instrument Explosion—a Study of Aircraft Cockpit Instruments."

⁶⁴ Ibid.

⁶⁵ Martin C. Hartel and Shu (Billy) C. Chou, Electronic checklist system, United States US5454074A, filed May 17, 1994, and issued September 26, 1995, <https://patents.google.com/patent/US5454074A/en>.

⁶⁶ Gavan Lintern, Tyler Waite, and Donald A. Talleur, "Functional Interface Design for the Modern Aircraft Cockpit," *The International Journal of Aviation Psychology* 9, no. 3 (July 1999): 225–40, https://doi.org/10.1207/s15327108ijap0903_3.

solutions were proposed to adjust these instruments, some of which were feasible in theory and also experimentally tested. For example, dials with adjustable ranges and graduation scales were adopted.⁶⁷ On the one hand, during phases of the flight when a certain parameter changes greatly, the pilot could adjust his/her dial to include a larger range, and thus larger graduation divisions, to constantly keep the result in range. On the other hand, during phases of the flight when a certain flight parameter is relatively constant, the pilot could decrease the dial's displayed range in order to get smaller divisions, and thus a higher precision of readouts. Techniques like this were made possible mainly by the combination of digital displays and traditional pointer dials: traditional dials aided by modern display technologies have become clearer from the perspective of the pilots while still maintaining their reliability.

Another change to cockpit designs at this time was their adaptations for increasingly more automated systems on board. While automation reduces the workload substantially, it is important that information about the status of these automated systems is continuously transferred to pilots.⁶⁸ For example, if there had been an anomaly in the airplane's control surfaces but the autopilot was automatically compensating for this anomaly without informing the pilots, crew members would have no idea of the actual situation of their airplane until the autopilot disengaged from the system. At this point, it is highly likely that the fault would become so severe that even the pilots could not save their airplane.⁶⁹ One solution that aircraft manufacturers adopted to inform pilots of what the autopilot is doing is to incorporate the autopilot's actions into the physical movements of the pilots' yokes and throttles.⁷⁰ In a hypothetical scenario, if an autopilot is compensating for an overweight of the starboard by rolling the airplane to the left, the pilots' yokes would reflect this change by displaying the movement as if this action were done by a real pilot. However, the effectiveness of this system is often questioned by scholars and pilots, as movements caused by these autopilot

⁶⁷ Hartel and Chou, Electronic checklist system.

⁶⁸ Donald A. Norman, "The 'Problem' with Automation: Inappropriate Feedback and Interaction, Not 'over-Automation,'" *Philosophical Transactions of the Royal Society of London. B, Biological Sciences* 327, no. 1241 (April 12, 1990): 585–93, <https://doi.org/10.1098/rstb.1990.0101>.

⁶⁹ Norman.

⁷⁰ André Luís da Silva, Pedro Paglione, and Takashi Yoneyama, "Cruising Autopilot for a Flexible Aircraft with an Internal Loop of Model Following," *Journal of Aerospace Engineering* 27, no. 2 (March 1, 2014): 202–14, [https://doi.org/10.1061/\(ASCE\)AS.1943-5525.0000277](https://doi.org/10.1061/(ASCE)AS.1943-5525.0000277).

actions tend to be subtle and even undetectable.⁷¹

At present, various aerospace intuitions and aircraft manufactures continue to discuss and test out new instrument designs. For example, current displays still require pilots to divide their time between looking at their instruments and looking outside, which could be extremely distracting in some special cases, such as landings on aircraft carriers.⁷² Thus, as shown in Figure 8,⁷³ a special kind of display called Heads-Up Displays



Figure 8.

The head-up display in an Airbus A350 approaching a runway, with a central circle guiding the pilot toward his/her ideal landing point

(HUDs) places the information directly in front of the crew members' eyes, enabling them to see the flight information without even looking downward. When approaching an aircraft carrier, for example, time and attention are very valuable for the pilot to make decisions. The time spent on looking down on the instruments might make the pilot miss the right time to land and cause catastrophic consequences. A HUD could solve this problem, as the pilot no longer needs to look down for flight information: basic parameters are all projected onto a transparent screen in front of him. In addition, the HUD is better equipped for non-ideal weather conditions, which is applicable to both commercial and military aircraft. When approaching a runway, the central target circle on the HUD would guide the pilot precisely to his/her landing point even if he/she cannot see it.⁷⁴ Figure 8 illustrates this situation under clear weather, but the central circle on the HUD would also guide the pilot through low-visibility weather, such as fogs and thunderstorms. In this way, the range of weather conditions under which aircraft can land could be further broadened.

71 Norman, "The 'Problem' with Automation."

72 Charles M. Enderby and Scott T. Wood, "Head-Up Display in Automotive/Aircraft Applications," SAE Technical Paper (Warrendale, PA: SAE International, February 1, 1992), <https://doi.org/10.4271/920740>.

73 *Live from the Airbus Cockpit—Another HUD Video Landing in Bergen Texted*, accessed September 16, 2020, https://www.youtube.com/watch?v=aAQgqR2WjTg&ab_channel=Fly%26Likew%2FSimulationandAviation.

74 Enderby and Wood, "Head-Up Display in Automotive/Aircraft Applications."

4. Conclusion

By studying cockpit instruments and their ergonomic considerations, this research offers fundamental insights into how humans interact with cockpit machine systems. Knowledge gained from this study would be instructive for the designs and implementations of next-generation aircraft cockpits, and would also benefit airline pilots by illustrating the internal mechanisms behind the instruments that they work with.

Insights from this study could also be extended to benefit other high-risk industries in which teamwork is essential and automation is shaping the ways in which operators perform their jobs. A typical example of such an industry is that of medical surgeons.⁷⁵ Although the jobs of surgeons might seem very different from those of pilots in that surgeons perform operations that are precise while pilots navigate through the skies on a scale of kilometers, they also share an impressive number of similarities. Indeed, just like a crew on a flight deck, a “crew” preparing to perform a surgery would also face the potential occurrences of errors, some of which can be lethal for the patient. Also, the “crew members” have to cooperate with their instruments in the execution of many high-risk tasks. This would lead to the key issue of interface designs and the mental states of the participants, which are addressed in this study. Also, the modernization of medical equipment has introduced a large number of highly-automated machines into the surgery room, aiding the “crew members” in ways that are very similar to those in the air. In fact, training programs concerning these issues in medical industries started soon after similar programs started in aviation; therefore, there is no doubt that this study of flight instruments and cockpit ergonomics would be instructive and applicable to the medical industry and other industries as well.

However, further research is needed to continue our understanding of the modern cockpit dynamics. Specifically, further research could provide more detailed analyses of the following sets of questions.

The first set of questions relates to the concept of automation. Precisely, how did and do different parties—NASA, Boeing, and operational airlines, for example—conceptualize the role of humans in a fully-automated machine? More fundamentally, how has the definition of automation evolved over time? If a captain assigns all flight tasks to other crew members, for example, can we say that regarding the captain, the plane is in complete automation? If at all, how and to what extent did the advent of automation change

75 Suzanne Gordon, Patrick Mendenhall, and Bonnie Blair O'Connor, *Beyond the Checklist: What Else Health Care Can Learn from Aviation Teamwork and Safety* (Cornell University Press, 2012).

pilots' abilities to control their aircraft? This cluster of questions seeks to explore how and the extent to which automation changed the environments in which crew members work, applicable not only to the aviation industry but to other areas as well. Since we are rapidly transitioning into an age dominated by Artificial Intelligence, it is crucial that we know how to collaborate and coordinate with automation. The ways in which pilots have cooperated and are cooperating with automated machines in their cockpits are good examples of models in which humans collaborate with machines in general. As such, a study of these questions would provide insights into the possible ways in which machines can be designed to cooperate with human operators or human "customers" in the future.

Secondly, the evolution of the concept of errors in CRM Trainings Programs is also worth exploring. How did the definition of errors change with the development of ever-smarter automation? In what ways did the human errors in cockpits change over time? What did these changes have to do with the aid of automation? What steps were taken to reduce these errors? These questions would shed light on the concept of error management and human errors, aiding professions in which errors in daily operations can have catastrophic consequences, in ways that are unconventional and instructive.

Lastly, the issue of priority assignments in the context of automation should also be discussed further. Specifically, should instructions from automation have the right to override human commands? What if two human operators are entering different commands, neither of which conform to the machines'? Should some machines have priorities over others? What are the historical attitudes of different stakeholders in the industry, such as Boeing, Airbus, Northrop Grumman, etc.? How have their different/same attitudes on these issues influenced the designs of their products? These issues are particularly evident after the recent Boeing 737-MAX accidents, in which two aircraft crashed due to conflicting information from two sources of the same information, killing over 300 people.⁷⁶

Overall, this study constitutes a limited step towards examining the complex human-machine dynamics in cockpits, but raises questions that have ramifications beyond the aviation industry. Such questions may well continue to garner scholarly attention in a world that is increasingly transformed by humans' interactions with machines and in which the efficiencies of different bodies interconnectedly depend on their working environments.

76 "Series of Failures behind Boeing Lion Air Crash," *BBC News*, October 25, 2019, sec. Business, <https://www.bbc.com/news/business-50177788>.

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Research Proposal

The Relationship Between Gut Microbiome, Hormones, and Acne Vulgaris Disease Presentation

Hui Lan

Author Background: Hui Lan grew up in China and attended the International School of Beijing in Beijing, China. Her Pioneer research concentration was in the field of Microbiology and titled "The Gut Microbiome."

Abstract

This paper proposes a three-part investigation on the impact of the gut microbiome and hormones on acne vulgaris presentation. The first investigation involves the infusion of human gut microbiome into age- and sex-matched germ-free HR-1 mice, which will be inoculated with *Cutibacterium acnes* (*C. acnes*) upon post-infusion stabilization. The second investigation uses age- and sex-matched germ-free HR-1 mice to analyze the effect of microbiome presence on disease presentation, with one group remaining as germ-free controls while another group receives human microbiome transplants and *C. acnes* inoculations. The final investigation aims to study the mechanism of gut microbiome-induced hormonal changes in disease presentation using germ-free androgen receptor knock-out (ARKO) and wild type mice. Mice will subsequently receive a human microbiome transplant, followed by inoculation with *C. acnes*. Inflammatory responses to all three parts will be measured via biopsy and immunohistochemical staining. Microbiome source and presence of gut microbiome are expected to affect disease presentation while the presence of androgen receptors will enhance inflammatory response.

1. Background Information

The human gut microbiome consists of a diverse community of bacteria, viruses, archaea, and fungi that inhabit the human body [1]. In recent years, studies on the impact of the human gut microbiome on human diseases, ranging from inflammatory bowel disease to schizophrenia, have increased. Estimates suggest as many as 25 to 50 trillion symbiotic microbiota cells in human adults [2]. As a result, a growing number of correlations have been observed and the view on microbiota has shifted from an entirely pathogenic to a commensal one. Healthy microbiomes typically consist of a large variation of commensal microbiota while unhealthy microbiomes have decreased diversity. However, even healthy individuals can have up to 99.5% dissimilarity in the species of microbiota that they host, which makes characterizing a healthy microbiome difficult.

Acne Vulgaris

Acne vulgaris is a common skin disorder that affects almost all adults and adolescents and is characterized by open and closed comedones, inflammatory papules, pustules, cysts, and nodules[3]. Such lesions are most commonly found on the face, chest, and back. Acne patients suffer from a large variety of disease severity, from mild comedonal acne to severe inflammatory and cystic acne. In recent years, several strains of the bacterium *Cutibacterium acnes* (*C. acnes*), previously known as *Propionibacterium acnes*, in the pilosebaceous ducts of the skin have been correlated to the presence of acne vulgaris. The development of acne lesions typically follows four steps: hyperseborrhea (increase in sebum production), *C. acnes* infection, pilosebaceous duct obstruction, and microcomedone formation. Alternative theories to the development of acne include excessive sebum production caused by hormonal imbalance, inflammation, follicular obstruction, and lifestyle factors. It is highly possible that both the skin and gut microbiomes play an imperative role in these processes.

The Skin Microbiome

The skin is the largest human organ that hosts a diverse microbiota with different constituents depending on the specific region. It contains layers, separated into the skin surface, epidermis, and dermis. The skin surface contains a variety of bacteria, viruses, and fungi—many of which provide vital functions such as protection against pathogens. The epidermis consists of spinous cells and basal cells, which help maintain the self-renewing properties

of the skin. Within the dermis are sweat glands, sebaceous glands, and hair follicles among various other components that contribute to the protective function of the skin. The sebaceous gland and hair follicle come together to form a pilosebaceous unit, which produces lipid-rich sebum. In acne vulgaris patients, the pilosebaceous units are filled with bacteria, namely *C. acnes*, which induce inflammatory responses that cause swelling and the formation of pustules. In particular, it has been found that certain strains, namely ribotypes (RT) 4 and 5, are of incredible abundance in patients[4].

Acne Vulgaris and Mental Health

Following an increase in mental health awareness, an undeniable link between acne and depression and anxiety has been identified [5]. Patients have been commonly found to have greater mental health impairment scores in comparison to other chronic conditions such as epilepsy and diabetes. Adolescent acne patients have also been found to have a two-to-threefold increase in suicide ideation as well as poor social functioning which can further attribute to the marked increase in suicide ideation [6]. Furthermore, the expensive treatment of acne and acne scarring, including expensive medications and therapies, can create an economic burden on families. Together, these severe consequences emphasize the need for a better understanding of the pathophysiology of acne for the development of more successful treatments.

Acne Vulgaris and Gut Microbiome

There has been a long-noted co-morbidity between acne vulgaris and gastrointestinal distress, implying that there may be a connection between gut microbiome dysbiosis, an imbalance in the bacterial community found in the human gut, and the development of acne [7]. Studies have shown that gastrointestinal dysbiosis leads to a leaky gut, where larger microbes are able to penetrate the gut lining and enter the circulatory system; similarly, it may also be possible that skin dysbiosis affects the ability of the skin to act as an effective defense barrier against pathogens like *C. acnes*. The possibility of using topical probiotics to combat the weakening skin barrier has also been suggested in the treatment of acne [8]. Recent studies have attempted transplanting skin microbiomes from healthy patients onto those with acne vulgaris, resulting in a decrease of inflammatory lesions; the results are preliminary, yet promising. *S. epidermidis*, a large component of the skin microbiome, was shown to reduce *C. acnes* induced lesions in mice when injected intra-lesionally [9].

Acne Vulgaris and Androgens

The connection between acne development and hormonal imbalance has also long been suspected due to its coinciding onset age at puberty [10]. One well-supported hypothesis is that an increase in androgen production can lead to abnormal epithelial desquamation and follicular obstruction as well as excessive sebum production, which causes comedones to close [11]. More specifically, androgen receptors in the epidermis respond to testosterone and DHT, which causes sebocyte proliferation [12]. This is physically presented as black or whiteheads. Upon comedonal closure, bacteria such as *C. acnes* will be entrapped and induce inflammatory responses which are responsible for the formation of lesions. It is also suspected that the hormonal fluctuations observed in puberty causes an increased production of sebum as these processes coincide. Furthermore, sebum is a suitable environment for the growth of bacteria such as *C. acnes*, which encourages an increase in inflamed papules and cysts. It is highly possible that this phenomenon triggers an inflammatory response as the *C. acnes*.

Gut Microbiome and Hormones

Past studies have found strong connections between the commensal gut microbiome community and hormones levels, particularly testosterone and dihydrotestosterone (DHT). One particular investigation detected elevated serum testosterone levels upon gut microbiome colonization in murine models of type 1 diabetes [13]. Female mice showed elevated serum testosterone after receiving the gut microbiomes of male mice. It is likely that members of the gut microbiota produce chemicals that stimulate or inhibit the production of hormones, and vice versa. Furthermore, it is possible that a combination of the gut microbiota and androgens can impact inflammation, which may have implications in the disease presentation of acne vulgaris [14]. This bi-directional relationship can also exist where the composition of hormones can alter microbiome conditions, such as pH, under which only certain microorganisms may be able to survive. Another study has found an estrogen-gut microbiome axis regulated by the gut microbiome secretion of beta-glucuronidase that has vast implications in estrogen-mediated disease [15]. However, there is currently no established connection between estrogen and the presentation of acne vulgaris.

Combined, these imply a fascinating relationship between the gut microbiome, skin microbiome, hormones, and acne vulgaris known as the gut-skin-brain axis [16]. This axis is extremely dynamic, and small alterations in any aspect can cause drastic alterations in others. There is little known

about the precise mechanism behind this axis; however, it is a promising field of study for furthering the understanding and treatment of cutaneous pathologies. This study aims to better understand the role of the microbiome-induced hormonal changes and inflammation in the development of acne vulgaris. The purpose of this study is to test the hypothesis that the gut microbiome induces hormonal changes which impact the skin microbiome. More specifically, these alterations in the gut microbiome in acne vulgaris patients influence their disease presentation and inflammation in response to *C. acnes*.

2. Significance of Research

The specific area of research remains untouched in the field yet has incredible significance in establishing a better understanding of acne vulgaris pathophysiology. Parodi et. al has investigated the connection between acne rosacea and small intestinal bacterial overgrowth, a gut microbiota disorder; numerous studies have examined the ways in which the gut microbiota can function as an endocrine organ and produce vital hormones [17]; Chehoud et. al has found that the gut microbiota influences the expression of genes on the skin [18]. However, none of these impactful studies have focused on the effect of the gut microbiome and gut microbiome-induced hormonal changes in the development and proliferation of acne. This study will provide a better understanding of the mechanisms behind hormonal shifts that may cause the onset of acne vulgaris and increase knowledge regarding the pathogenesis of acne vulgaris.

Furthermore, this study is a novel investigation of the role of androgens acne vulgaris inflammation using the androgen receptor knock-out (ARKO) mouse model. It will evaluate the advantages of this model in studying the connection between androgens and skin inflammation.

3. Methodology

3.1 Effect of microbiome source on disease presentation

To test the hypothesis that the gut microbiota impacts the disease presentation and profile of acne vulgaris patients, germ-free HR-1 mice of the same age and sex, recently found to have an inflammatory response to *C. acnes* that reflect human acne [19], will be used. 24 HR-1 mice will be separated into two groups, acne and non-acne, with 12 mice each. Mice within each group will be separated into three sections, each with a different donor to account for human gut microbiome variety. Human microbiomes will be

introduced into mice using the fecal transplantation technique of gavage from volunteers with and without acne vulgaris into the acne and non-acne groups, respectively, at a rate of 0.15mL per mouse. Acne volunteers will be selected based on acne severity and absence of other disorders, especially those known to alter the gut microbiome. Non-acne volunteers will be chosen based on no previous history of acne vulgaris and the absence of current gastrointestinal disorder. Fecal microbiome diversity will be calculated using the Shannon Index to account for both diversity and distribution. Prior to transplantation, samples will be frozen at -80°C in liquid nitrogen for preservation as modeled from [20].

Free testosterone and DHT will be measured via blood sampling from the tail vein prior to and three days after fecal transplantation to determine the impact of the microbiome on hormone levels. Hormone levels will be tested every third day until stabilization, at which 10^9 colony forming units (CFU) of *C. acnes* will be injected into the backs of the acne and non-acne mice. *C. acnes* will be obtained from Fitz-Gibbon (UCLA) who has previously isolated RT4 and RT5. Response of mice to *C. acnes* will be measured by the presence of inflammatory biomarkers, such as cytokines, neutrophils, IL- 1β , myeloperoxidase, and MMP-9 and physical symptoms such as inflammatory lesions and microcomedones in biopsy near inoculation site and graded on a semi-quantitative scale. Subsequent hematoxylin and eosin immunohistochemical staining will be conducted using standard methods. All of the measurement standards are known to be prominent in HR-1 mice with *C. acnes* [19]. Differences in responses may coincide with differences in gut microbiota and hormonal levels. Inflammatory biomarkers and hormone levels will be measured prior to inoculation and at two weeks after inoculation. Lesions will be harvested and centrifuged and supernatants will be stored at -80°C for cytokine analysis by ELISA, as previously performed [21].

3.2 Effect of gut microbiome presence on disease presentation

A secondary investigation will be conducted to observe the relationship between the presence of a microbiome and the development of acne vulgaris. Two groups of germ-free HR-1 mice of the same sex and age will be used. One group will receive microbiome transplants from a human donor with acne vulgaris. The other group will remain germ-free. Transplantation will occur via oral gavage at 0.15mL per mouse. Both groups will be inoculated with *C. acnes* at eight weeks of age. Androgen levels and inflammatory biomarkers, as identified in section 3.1, will be measured prior to inoculation and two weeks after. Mice will be maintained in gnotobiotic isolators until three weeks after inoculation. Germ-free status will be monitored

by quantitative polymerase chain reaction (PCR) for 16S ribosomal DNA (rDNA), as modeled by Uchiyama, et. al. [22].

Inflammatory biomarkers in both groups will be evaluated prior to inoculation and two weeks after inoculation with *C. acnes* using skin biopsy from region close to inoculation site. As detailed in previous sections, lesions will be harvested, centrifuged, and supernatants will undergo cytokine analysis by ELISA. Further analysis will occur via biopsy immunohistochemically for neutrophils, IL-1 β , myeloperoxidase, and MMP-9. Physical presentation and immunohistochemical results will be graded on a semi-quantitative scale as described in experiment 1.

Donor gut microbiomes will be sequenced using high-throughput sequencing of 16S rRNA and murine gut microbiomes will be sequenced using the same method after transplantation to determine the extent to which the donor microbiome was able to colonize the previously germ-free mice. Murine gut microbiomes will be sequenced a second time at two weeks after inoculation with *C. acnes* to determine changes in the microbiomes and to accurately correlate the microbiome with the inflammatory responses. Non-acne mice groups will receive the same microbiome for transplantation.

3.3 Mechanism of gut microbiome-induced hormonal changes in disease presentation

To test the hypothesis that the gut microbiome induces hormonal changes that then affect acne vulgaris disease presentation, male age-matched germ-free androgen receptor knock-out (ARKO) and wild type mice will be used. Prior to gut microbiome transplantation, germ-free status will be maintained as described in section 3.2. One group of 12 sex and age-matched ARKO mice will receive gut microbiome transplant from a human donor with acne vulgaris from experiment 1 via oral gavage at 0.15mL per mouse. 12 wild type mice will receive identical treatment. Microbiome will be characterized prior to and after transplantation using 16S rRNA high-throughput sequencing and subsequently evaluated using the Shannon Index. Testosterone and DHT levels will be examined via blood sampling from the tail vein every other day for two weeks. Thereafter, inoculation and detection of inflammatory biomarkers will be conducted as previously described. Refer to Figure 1 for investigation sequence.

4. Expected Results

It is expected that the microbiome source will impact the disease presentation of acne vulgaris on HR-1 mice. Specifically, the mice with microbiomes

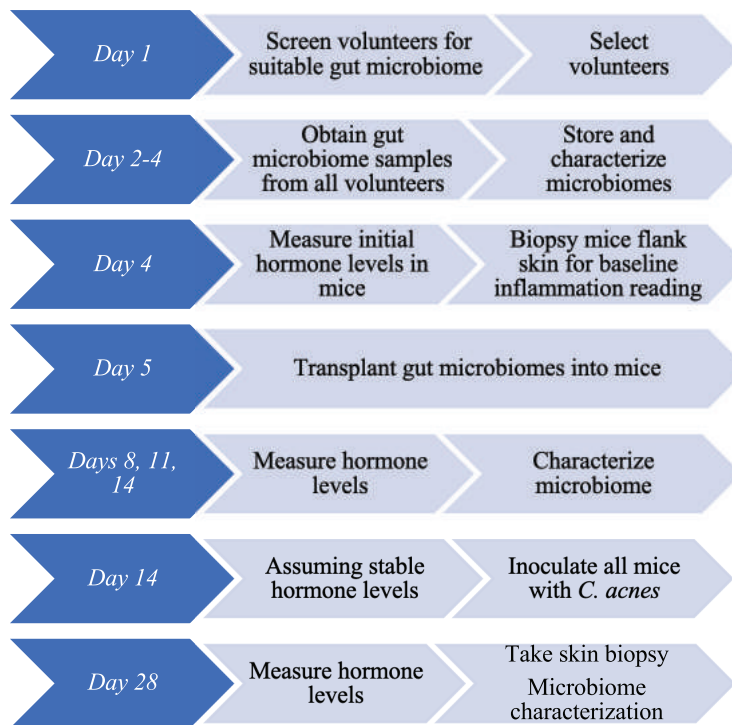


Figure 1.

*Timelines of investigations 1, 2, and 3 from sections 3.1, 3.2, and 3.3, respectively. The same timeline and donor (acne/non-acne) microbiomes will be followed for all three investigations. Investigation 1 compares the impact of gut microbiomes on response to *C. acnes* of acne patients and non-acne volunteers, investigation 2 evaluates the impact of the presence of a gut microbiome, and investigation 3 associates the connection between gut microbiome source and inflammatory response.*

from acne vulgaris patients will produce a greater inflammatory response, leading to a greater concentration of inflammatory markers in the same region as well as a larger lesion as opposed to those with microbiota from healthy volunteers. Furthermore, the androgen levels in acne vulgaris mice are expected to change and then stabilize with the colonization of *C. acnes*. It is also expected that the lesions in the non-acne group will diminish at a faster rate, if lesions develop at all. If the acne microbiome increases androgen production, then an increase in androgen concentration would be expected after microbiome transplantation, and vice versa.

In experiment 2, it is expected that the presence of a microbiome will increase the inflammatory response since certain bacterial species regulate and influence inflammatory responses. To confirm this, we anticipate greater inflammatory responses in the mice that received microbiome transplants,

which will manifest as an elevation in cytokines, neutrophils, IL-1 β , MMP-1, and myeloperoxidase and lesion size.

The mechanism behind the results of the previous experiments is expected to be hormonal changes induced by gut microbiome alterations. To confirm such a mechanism, we expect greater amplification in the hormonal measurements in the mice that received microbiome transplants in comparison to those that remained germ-free.

As the growth and development of the ARKO mouse model is not entirely established in the literature, which may complicate predictions and understanding of the responses to gut microbiome transplantations since there may be mechanisms affected by the lack of androgen receptor. Furthermore, this lack of androgen may create a different gut environment and suit a different population of microbes for colonization. It therefore may be unclear whether results are caused by the lack of androgen or a change in the gut microbiome due to the lack of androgen. The serum testosterone levels are expected to be lower in ARKO male mice, as discussed previously [23].

As this research approach is novel, there are many possible outcomes. If the presence of androgen leads to an increase in inflammation, then we would expect to see a greater inflammatory response and increase in inflammatory markers in wild type mice. Inversely, if the absence of androgens increases inflammation, then greater inflammation would be expected in ARKO mice.

5. Limitations

It is important to acknowledge several limitations in this proposed study. Although murine models serve as an excellent method for replicating and investigating cellular processes, there may be marked differences between the mouse model observations and the human cellular pathway. Specific to the study of gut microbiota, the digestive system of mice is physically different to that of humans and may lead to a different colonized community of microbiota.

Furthermore, since murine models lack human-like skin, it is difficult to replicate the occurrence of acne vulgaris. Although HR-1 mice are the closest model, they are by no means perfect predictors of human disease, especially of acne vulgaris—a disease unique to humans. This proposed study involves inoculation with the *C. acnes* bacterium below the dermis, which is unlike human acne vulgaris where *C. acnes* populations are found in the epidermis and dermis. Thus, there may be differences in inflammatory responses.

In section 3.3, it is possible that the ARKO mice will have developmental differences in comparison to wild type mice due to the lack of androgen

receptors, may impact data interpretation. Finally, although a variety of gut microbiomes from donors will be chosen to encompass as much diversity as possible, true representation is not possible as there are incredible variations in gut microbiota from person to person. Thus, results should not be generalized.

6. Conclusion

Acne vulgaris is a common skin disease characterized by open comedones, closed comedones, and lesions spanning from the face to the chest and back. Acne is commonly known to be related to the onset of puberty, hormones, follicular obstruction, and lifestyle factors such as diet. However, the exact mechanisms of several pathogenesis theories remain uncertain. The reason for acne prevalence in certain individuals over others is also unclear. As individuals presenting with severe acne have been found to have decreased social functioning and a higher rate of suicide ideation, it is imperative to establish a stronger understanding of the pathogenesis of acne so that more medications can be developed. One possible cause of an amplified response to *C. acnes* is the variation in gut microbiomes. Since the gut microbiome plays a key role in numerous vital processes, it is possible that the gut microbiome can impact the development of acne vulgaris.

This study aims to study the connection between the gut microbiome and the skin's response to acne vulgaris as well as the relationship between androgen production and inflammation as a possible pathway for the gut-skin connection. Germ-free HR-1 mice will receive microbiome transplants from volunteers with and without acne. Mice will be monitored for hormonal changes and subsequently inoculated with *C. acnes*. Inflammatory response will be measured thereafter via immunohistochemical staining and cytokine detection. A second cohort of germ-free and conventionally raised HR-1 mice will be inoculated with *C. acnes*. The aforementioned measurements will be taken. Finally, to better understand the relationship between androgens and inflammation, a third group of germ-free ARKO and wild type mice will undergo the same procedure involving microbiome transplants from volunteers with acne. Inflammatory response will be determined as previously stated.

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A Monte Carlo Simulation of the Single-Electron Transistor

Irene Chen

***Author Background:** Irene Chen grew up in the United States and attended Leland High School in San Jose, California. Her Pioneer research concentration was in the field of Engineering and titled "Nanotechnology."*

Abstract

The purpose of this paper is to examine the single-electron transistor (SET) through modeling and simulation. The single-electron transistor is a nanoelectronic counterpart of the field-effect transistor, and it is unique in its use of quantum effects to induce the tunneling of a single electron. Hence, the single-electron transistor is a novel device that has the potential to resolve the hindered progress in transistor development by increasing speed and reducing power consumption. This paper focuses on modeling a pre-existing, realistic single-electron transistor using a Monte Carlo approach. In particular, the effects of temperature, gate capacitance, tunneling resistance, and source-drain voltage on gate current-gate voltage (IV_g) properties are analyzed. The simulation developed in this research presents a reliable model for metallic single-island SETs and provides a foundation for further device simulation and design.

1. Introduction

Transistors are semiconductor devices generally consisting of at least three terminals that are used to amplify or switch electronic signals. These devices are the foundation of modern electronic devices. Since the mid-20th century, significant progress has been made in producing more effective transistors. The metal-oxide-semiconductor field-effect transistor (MOSFET) was fabricated by John Atalla and Dawon Kahng in 1960 to overcome the surface states that blocked electric fields from the semiconductor material, and the device has

since become the most commonly used type of transistor [1]. It has three conducting electrodes: a source, a gate, and a drain. The source contains the electrons that are carried by the current to the drain. The gate is where voltage can be applied to create an electrical field to attract and mobilize the electrons. If a voltage is applied at the gate, then current flows from the source to the drain, signifying an “on” state. If a voltage is not applied, then there is no current, signifying an “off” state [2].

Achievements have been made in decreasing the size of transistors. Scaling down transistor size increases the number of devices per unit area, thereby increasing the number of operations per second. Therefore, smaller transistors have led to increased speed, increased functional complexity, and reduced power consumption [3]. The famous Moore’s Law states that the number of transistors that can be fitted into an integrated circuit doubles approximately every two years. However, Gordon Moore has acknowledged the shortcomings of his prediction; it “can’t continue forever” [4]. Because of the exponential nature of his model, the number of transistors would eventually reach infinity, which is impossible. Nvidia’s CEO, Jensen Huang, has recently claimed that Moore’s Law died in 2019. According to Huang, “Moore’s Law used to grow at ten times every five years,” but “right now Moore’s Law is growing a few percent every year . . . so Moore’s Law has finished.” Other tech industry experts agree that the semiconductor industry is slowing down [5]. However, nanotechnology has emerged as a promising field and may offer solutions to this dead end with the development of the single-electron transistor.

Like its field-effect transistor counterpart, a single-electron transistor consists of a source, gate, and drain. The source supplies electrons to the drain. At the gate, a voltage bias is applied to produce an electric field and mobilize electrons. An “on” signal is generated if a voltage is applied at the gate, causing current to flow from the source to the drain. An “off” signal is generated if a voltage is not applied, resulting in no current. However, the single-electron transistor is unique in its use of quantum tunneling to produce a current signal of a single electron. Whereas a stream of electrons flows from the source to the drain in a conventional field-effect transistor, individual electrons in the source tunnel through physical barriers into an isolated quantum dot structure and then out of the dot to the drain in a single-electron transistor. As a result, single-electron transistors are known for their enhanced speed and reduced power consumption compared to field-effect transistors [2].

The development of the single-electron transistor has met many challenges, including room temperature operation, large-scale integration, large-scale production for commercial use, background charge, cotunneling, and

linkage with the environment [6, 7, 8, 9]. Because a single-electron transistor must satisfy certain conditions to function without random tunneling, it must operate at a very low temperature or have a minimal capacitance. In the case of room temperature operation, the charging energy has to be greater than the thermal energy at room temperature. Additionally, the resistance of the junctions must be greater than the quantum resistance. It is important to note that the dimensions and the structural design of the device affect the value of the effective capacitance and resistance and ultimately, room temperature functionality. Hence, the current focus is on scaling and designing the nano-islands [3].

Even though room temperature operational single-electron transistors have been successfully fabricated, more progress has yet to be made to implement single-electron transistors that behave like conventional MOSFETs. Researchers have turned to modeling and simulation to investigate the behavior of single-electron transistors in greater detail. There are three major simulation methods: SPICE macro-modeling, Monte Carlo, and Master Equation [3, 10, 11]. With SPICE macro-modeling, one can model the IV characteristic of a single-electron transistor the same way a MOSFET is modeled in SPICE. Although this technique is considerably faster than the Monte Carlo method or the Master Equation, it does not capture the interaction between adjacent transistor devices and the Coulomb blockade effect [3, 10]. The Monte Carlo method begins with all possible tunneling events. The probabilities of the tunneling events are calculated. The events are weighted according to their probabilities, and one possible event is chosen at random. The process is executed repeatedly to model electron transport. The Master Equation approach uses a system of equations to describe the charge transport processes in single-electron circuits. The system is solved as a matrix exponential. However, it becomes difficult to solve; the matrix becomes too large due to an infinite number of possible states [10].

In this research project, the goal is to obtain a better understanding of the single-electron transistor, particularly its electron tunneling properties and IV characteristics under various conditions for a single-island device. A Monte Carlo simulation is developed in MATLAB to evaluate the effect of temperature, gate capacitance, tunneling resistance, and source-drain voltage on gate current-gate voltage (IV_g) characteristics for single-island devices. Among the modeling techniques mentioned previously, the Monte Carlo approach is selected for this project because it is capable of demonstrating the Coulomb blockade effect and is more efficient than the Master Equation in computing transport configurations. By examining single-electron transistor functionality, this research can provide guidelines for device design and pave the road for future studies of single-electron devices.

2. Theory of Single-Electron Transistors

As its name suggests, the single-electron transistor involves the tunneling of a single electron from the source to the drain, which increases the speed and reduces the power consumption of the device. A single-electron transistor consists of a source, gate, and drain like a traditional transistor, but this device is unique in its use of quantum effects. The electrons are able to tunnel from the source through the first tunnel junction into an isolated quantum dot structure and then tunnel out of the quantum dot through the second tunnel junction to the drain. To predict the IV characteristics of metallic SET devices, the orthodox theory is employed. It is based on a semi-classical approach with the following assumptions [3, 12]:

1. The time for electron tunneling across the barrier is negligibly small compared to the time interval between successive tunneling events.
2. The electron energy quantization inside the conductors is ignored; the electron energy spectrum is treated as continuous.
3. Coherent quantum processes consisting of several simultaneous tunneling events, also known as cotunneling, can be ignored for a system with junction resistances greater than $6.5 \text{ k}\Omega$.

A basic structure of a single-island SET (Figure 2.1) and a schematic diagram (Figure 2.2) are shown below. For a single-electron transistor device to function as intended, the tunneling of electrons must be controlled. This is achieved by the Coulomb blockade, whose conditions are examined in Section 2.1.

2.1 Coulomb Blockade

The Coulomb blockade can be explained using the analogy of the interaction between an initially neutral metallic sphere and a single electron. The sphere and the electron are attracted to each other. If they are brought into

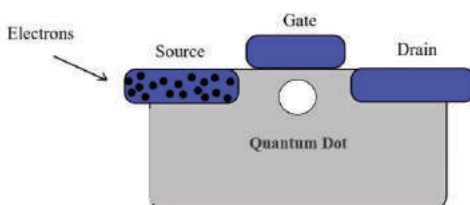


Figure 2.1. Basic Structure of a Single-Island SET Device. Adapted from [2].

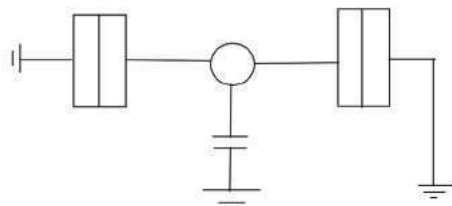


Figure 2.2. Schematic Diagram of a SET. Adapted from [3].

contact, then the electron would join the sphere and leave a negative charge with magnitude e . Due to the electric field created around the sphere, any other electron in the presence of the sphere-electron system would experience a strong repulsive force [7]. Similarly, an electron in a quantum dot would exert a repulsive force on another electron in the vicinity of the dot, thereby preventing arbitrary tunneling to and from a quantum dot. This effect can be measured by the quantum dot's capacitance [2]:

$$C = G\epsilon d \quad (2.1)$$

where G is the geometrical term, ϵ is the permittivity of the material surrounding the dot, and d is the diameter of the dot. Note that $G = 2\pi$ for spherical structures, so:

$$C = 2\pi\epsilon d \quad (2.2)$$

for a spherical quantum dot. The energy required to add one electron to the dot is equivalent to the charging energy [2]:

$$E_C = e^2 / 2C \quad (2.3)$$

Based on this equation, a very small capacitance yields a high charging energy, which prevents electrons from being transported simultaneously.

The thermal vibrations of the atoms in the lattice can provide the additional energy for an electron to tunnel through the barrier. This energy is equal to $k_B T$, where k_B is Boltzmann's constant (1.38×10^{-23} J/K). Therefore, the charging energy must be significantly higher than the thermal energy of the electron to perform the Coulomb blockade [2]:

$$E_C \gg k_B T \quad (2.4)$$

By convention, the effects are assumed to hold true if the charging energy is larger than ten times the thermal energy [2, 12]:

$$E_C > 10k_B T \quad (2.5)$$

In addition, Heisenberg's uncertainty principle is considered. The uncertainty principle states that the more precise an object's position, the less precise its momentum. Due to the connection between momentum and kinetic energy, a relationship between the measurement time and the system's energy can be deduced [2]:

$$\Delta E = h / \Delta t \quad (2.6)$$

where h is Planck's constant ($h = 6.62 \times 10^{-34} \text{ J}\cdot\text{s} = 4.14 \times 10^{-15} \text{ eV}\cdot\text{s}$). The measurement time Δt is equivalent to the time constant of the capacitor [2]:

$$\Delta t = R_t C \quad (2.7)$$

where R_t is the tunneling resistance. Since $\Delta E < E$, equations (2.2) and (2.4) can be combined to arrive at the following relationships [2, 6, 7, 8]:

$$h / R_t C < e^2 / 2C \quad (2.8)$$

$$R_t \gg h / e^2 \quad (2.9)$$

$$R_t \gg 25.8 \text{ k}\Omega \quad (2.10)$$

Thus, the tunneling resistance must be significantly greater than the quantum resistance ($h / e^2 = 25.8 \text{ k}\Omega$) to maintain electron isolation in the quantum dot.

A voltage is applied to the gate to create an electric field and change the potential energy of the dot with respect to the source and drain, causing electrons from the source to be attracted to the dot and electrons in the dot to be attracted to the drain. The electrons would tunnel through the Coulomb energy barrier, and current would flow from the source to the drain. The applied voltage must overcome the energy of the Coulomb blockade for the electrons to tunnel. The minimum potential energy necessary is equal to the energy of the Coulomb blockade, and the minimum voltage can be determined [2]:

$$V = E_C / e \quad (2.11)$$

$$V = (e^2 / 2C) / e \quad (2.12)$$

$$V = e / 2C \quad (2.13)$$

In summary, the Coulomb blockade regulates the electron transport process, and its three conditions are listed below:

1. The charging energy must be significantly higher than the thermal energy of the electron:

$$e^2 / 2C \gg k_B T$$

2. The tunneling resistance must be significantly greater than the quantum resistance:

$$R_t \gg 25.8 \text{ k}\Omega$$

3. The gate voltage must be equal to or greater than the charge magnitude of an electron divided by twice the capacitance of the island:

$$V = e / 2C$$

Considering the first condition above in the case of room temperature operation, the charging energy has to be greater than at least ten times the thermal energy at room temperature (approximately 300 K). Therefore, the effective capacitance must be extremely small: on the order of 10^{-18} F or lower. The effective capacitance includes the capacitances of the nano-island and the junctions, which must all be on the same order. However, the capacitance of the island is the most critical factor. The overall capacitance of the device can be minimized by limiting the capacitance of the nano-island, and the nano-island should be designed to be less than 10 nm (assuming that the quantum dot is spherical) [3]. Additionally, the tunnel junction width should be less than 2 nm since a smaller dimension minimizes the junction capacitance, thereby producing a large charging energy, and yields an adequately high tunneling probability. Given the relationship between voltage and charging energy, a large charging energy must be accompanied by a large source-drain voltage (V_{sd}) on the order of 0.1 to 1.0 V to enable electron tunneling; the equation for the threshold voltage is listed above. When V_{sd} is less than the threshold voltage, electron tunneling events can still occur with the modulation of the gate potential, which leads to Coulomb oscillations [12]. The next section will focus on Coulomb oscillations.

2.2 Coulomb Staircase

The Coulomb staircase occurs when the tunneling rate in junction 1 is much lower than that in junction 2. This condition can be achieved if the width of junction 1 is greater than the width of junction 2. In this case, when V_{sd} meets or exceeds the threshold voltage, the electrons can overcome the charging energy of junction 2 and tunnel through the junction. The potential of the island decreases after this process; electron tunneling may become favorable in junction 1. However, the tunneling rate in junction 1 will be lower than the tunneling rate in junction 2 because the transition probability through

junction 1 is much smaller than the transition probability through junction 2. Hence, junction 1 is the limiting factor that determines the tunneling rate and the current. As V_{sd} is increased, electrons can overcome the second charging energy in junction 2. Now there will be a current pathway across the device with the island in charge states $+e$ and $+2e$. The abrupt addition of another current pathway in charge-state phase space leads to the Coulomb staircase phenomenon [12].

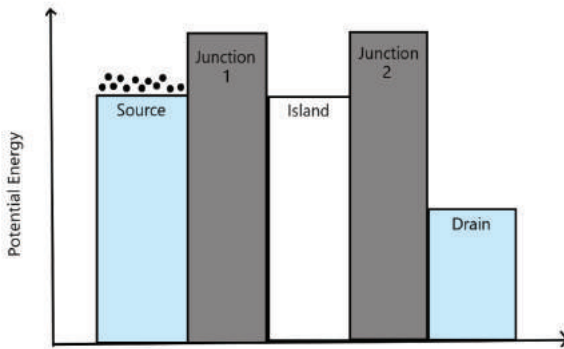
2.3 Coulomb Oscillations

Several studies of single-electron transistor devices have shown evidence of the Coulomb-oscillation phenomenon in IV_g characteristics [3, 12, 13, 14]. For a device with a constant and small source-drain voltage bias, the gate voltage can be increased to overcome the energy at the first junction, increasing the tunneling probability at each junction. If the electron successfully tunnels through both junctions, then a net current flow is generated in the device. However, subsequent tunneling across the second junction decreases by additionally increasing the gate voltage, as the island's occupied levels and the available levels in the left electrode become misaligned [12, 13]. This factor means that tunneling is also blocked in the first junction until the gate bias is large enough to overcome the second charging energy. Due to the Coulomb-blockade patterns in the junctions, a periodic variation in source-drain current known as the Coulomb oscillation effect occurs [3, 13]. The period of the Coulomb oscillation in IV characteristics of a single-island device can be calculated as follows [13, 14]:

$$V = e^2 / C \quad (2.14)$$

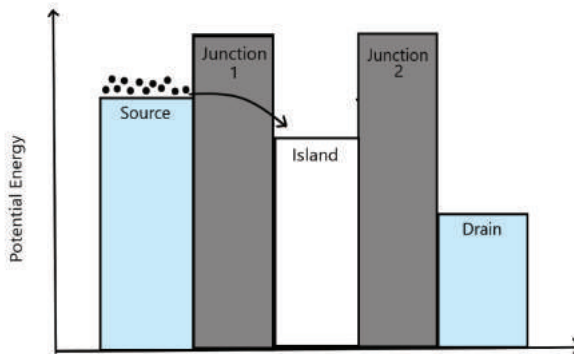
Figures 2.3 and 2.4 on the following pages provide a reference to the electron tunneling properties discussed as part of the theory of single-electron transistors. To sum up this section, the Coulomb blockade and the Coulomb oscillation are two fundamental features of the SET device, and they are connected to the electron tunneling phenomenon in single-electron transistors. The upcoming section will focus on how to observe these characteristics through a Monte Carlo modeling method.

(a)



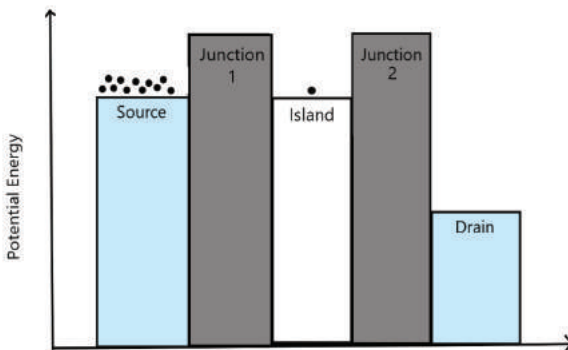
The SET is in an OFF state. No voltage is applied to the gate, and it is energetically unfavorable for electrons in the source to tunnel through the first junction to the quantum island.

(b)



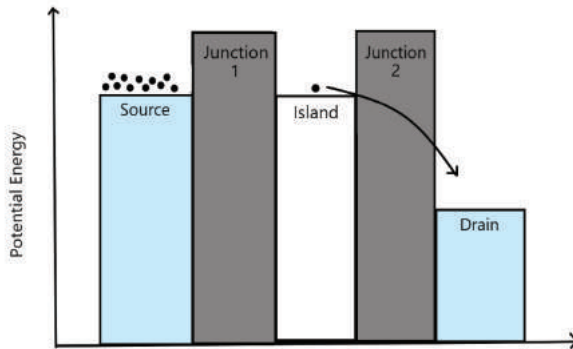
The SET is in an ON state. Now, an adequate gate voltage is applied, which can overcome the charging energy of the island.

(c)



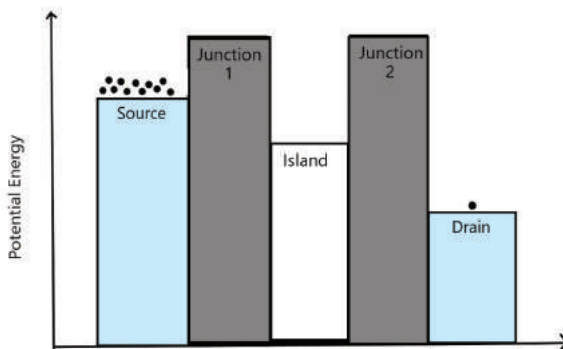
At this step, one electron from the source has tunneled through the first Coulomb blockade to the island. As a result, the potential energy of the dot increases further to overcome the Coulomb blockade of the second junction.

(d)



Since a lower energy state is more favorable, the island has the tendency to tunnel through the second junction to the drain. The voltage must overcome the Coulomb blockade of the second junction.

(e)



Finally, the electron has tunneled from the island through the second junction to the drain, where the potential energy is lowest.

Figure 2.3.

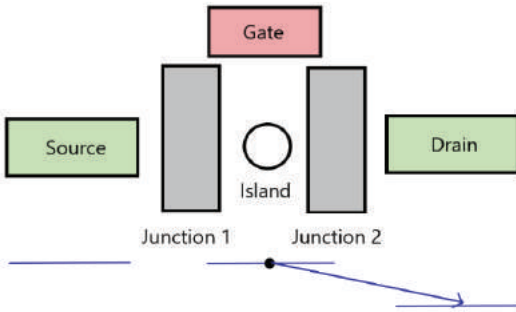
Potential Energy Model of a Single-Island SET. Adapted from [2].

3. SET Device Structure, Model, and Simulation Method

3.1 The SET Device Structure and Model

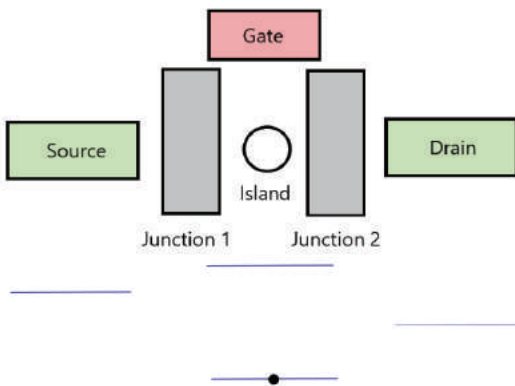
The device structure used in this project is shown in Figure 3.1. It is composed of a metal source electrode, a metal island, a metal drain electrode, and a metal gate electrode. Additionally, there is a tunnel junction between the metal source electrode and the metal island and another one between the metal island and the metal drain electrode. The source electrode is powered by a voltage source V and the gate electrode is connected to another voltage source V_g . The drain electrode is grounded. The physical model of the SET device is the same as the one shown in Figure 3.1.

(a)



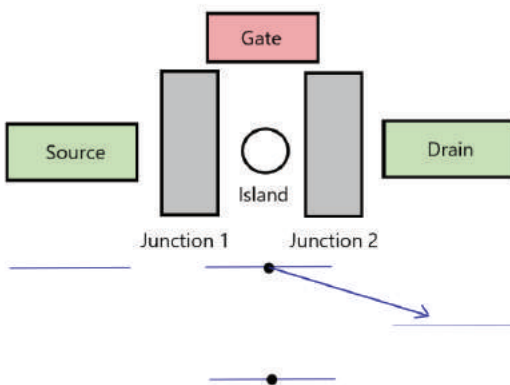
Upon increasing the gate voltage, electrons tunnel through junction 1. The increased potential bias across junction 2 caused by the tunneling makes subsequent tunneling highly probable at junction 2.

(b)



By increasing the gate voltage further, subsequent tunneling across junction 2 decreases due to misalignment of the island's occupied levels with available levels in the left electrode.

(c)



At this point, electron tunneling is blocked in junction 1 as well until the gate bias is increased sufficiently to overcome the second charging energy of the island.

Figure 2.4.

Energy Diagram of SET Under Increasing Gate Voltage Conditions Adapted from [12].

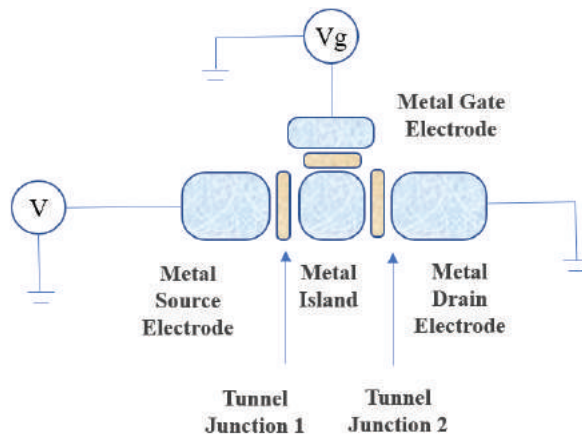


Figure 3.1. The SET device employed in this project

3.2 The Monte Carlo Method

The Monte Carlo method is a computational algorithm that can be used in various applications, and it is based on repeated random sampling to approximate solutions. This method tends to be employed when there are no analytical or numerical solutions or when these solutions are too difficult to implement [15]. The fundamental steps of the Monte Carlo method are: (1) perform random sampling, (2) conduct a large number of tests on a computer, and (3) draw statistical conclusions from the model outputs. First, random numbers uniformly distributed between 0 and 1 are generated. The continuous range $[0, 1]$ is essential, for it enables the random numbers to be transformed into real values that follow any distribution of interest. This operation can be easily performed on modern-day computers, as many arithmetic random-generators have been developed for computer-based random generation. Second, the uniformly distributed random variables are transformed into random variables that follow a particular distribution. There are several methods for such a transformation. The simple and direct transformation is the inverse transformation method. For this method, each random variable is assigned a probability to yield a distribution function [15, 16]. A cumulative distribution function can be obtained by integrating the original distribution function. The cumulative function essentially takes into account the probability from 0 to the variable of interest. Then the inverse of the cumulative function is taken so that a number can be selected at random again while considering its probability of being chosen [16].

3.2 Application of the Monte Carlo Method in Single-Electron Transistors

The behavior of the single-electron transistor is governed by the tunneling rate of electrons through junctions between electrodes or islands. Determining the tunneling rates is essential for the Monte Carlo simulation as they are used to calculate the tunneling time to select the tunneling event among all possibilities. Here, the Orthodox theory is applied to derive the tunneling rates of metal island SETs through assumptions and simplifications. By ignoring the quantization of energy in the island, the tunneling rate can be expressed as in Equation 3.1 [17]. It is necessary to note that this simplification does not pertain to semiconductor island SETs.

$$\Gamma = \frac{-\Delta F}{e^2 R_T \left(1 - \exp\left(\frac{\Delta F}{k_B T} \right) \right)} \quad (3.1)$$

where ΔF is the free energy change, R_T is the tunnel resistance, e is the electron charge magnitude, k_B is the Boltzmann constant, and T is the temperature.

The free energy difference for the various possible tunneling events is given by the following equations [17]:

$$\Delta F_1^\pm = \frac{e}{C_\Sigma} \left\{ \frac{e}{2} \pm Q \mp (C_G + C_2)V \pm C_G V_G \right\} \quad (3.2)$$

$$\Delta F_2^\pm = \frac{e}{C_\Sigma} \left\{ \frac{e}{2} \mp Q \mp C_1 V \mp C_G V_G \right\} \quad (3.3)$$

The definitions for each term in the equations above are provided below:

- ΔF_1^+ : free energy change for the electron tunnel through C_1 from source to island
- ΔF_1^- : free energy change for the electron tunnel through C_1 from island to source
- ΔF_2^+ : free energy change for the electron tunnel through C_2 from island to drain
- ΔF_2^- : free energy change for the electron tunnel through C_2 from drain to island
- Q : charge in the island
- C_Σ : sum of C
- C_1 : capacitance of junction 1
- C_2 : capacitance of junction 2

- C_g : capacitance of gate
- C_{Σ} : sum of C_1 , C_2 , and C_g
- V : voltage applied to the source electrode
- V_g : voltage applied to the gate electrode

After the tunneling rates are determined, the tunneling times τ are computed for each event by using the equation below [10]. Note that r is a random number in the domain $[0, 1]$:

$$\tau = \frac{\ln(r)}{\Gamma} \quad (3.4)$$

The event with the shortest time will be taken as the actual tunneling event. Charge and voltage states are updated for each new event, and new tunneling rates are computed. These steps are repeated to yield a time t_1 (that an electron takes to tunnel into the dot) and a time t_2 (that an electron takes to tunnel out of the dot). These times are added to produce a total time t for each tunneling occurrence. Since current is defined as the amount of charge flowing across an area per unit of time, the current of the single-electron transistor model is calculated as:

$$I = e / t_{\text{avg}},$$

where e is equal to the charge magnitude of an electron and t_{avg} is equal to the average of the total times. The device's voltage is an independent variable that can be adjusted. Finally, an IV graph can be produced.

A MATLAB program is written for the Monte Carlo simulation according to the flow chart shown in Figure 3.2. Temperature, tunnel resistance, capacitance, and voltage are treated as independent variables to simplify the simulations.

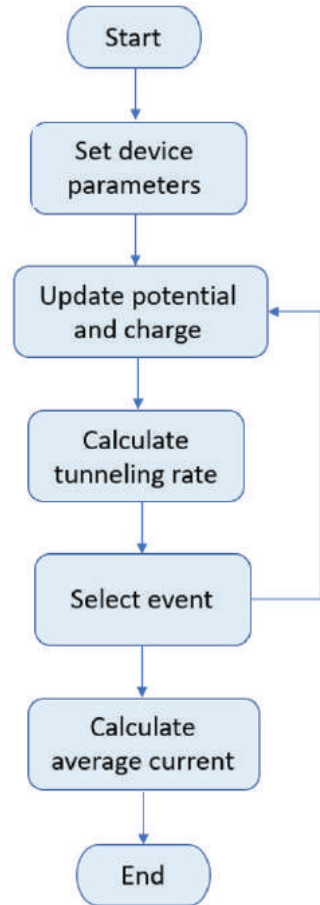


Figure 3.2.
Monte Carlo Simulation
Flow Chart

4. Model Verification

Two cases are simulated by setting the device parameters as indicated in Table 4.1 to validate the accuracy of the Monte Carlo model. The two cases are chosen from prior research conducted by Wu to facilitate model comparison and verification [18]. In the simulations, the gate voltage V_g was increased incrementally by 0.001 Volt and for each voltage 200,000 iterations were performed to obtain an accurate model for current.

For the first case, the IV graphs for this model and Wu's model correlate with each other, as shown in Figure 4.1. For the second case, this model has a similar response to Wu's model with the same oscillation frequency but a slightly higher peak current. With the verification of the two cases, the model is validated for studying the effects of device parameters on SET performance.

Table 4.1. Conditions for Verification Cases

	Case 1	Case 2
T	0 K	30 K
R_{T1}	100 M Ω	100 M Ω
R_{T2}	100 M Ω	100 M Ω
C_1	1.6 aF	1.6 aF
C_2	1.6 aF	1.6 aF
C_g	3.2 aF	3.2 aF
V	0.01 V	0.01 V

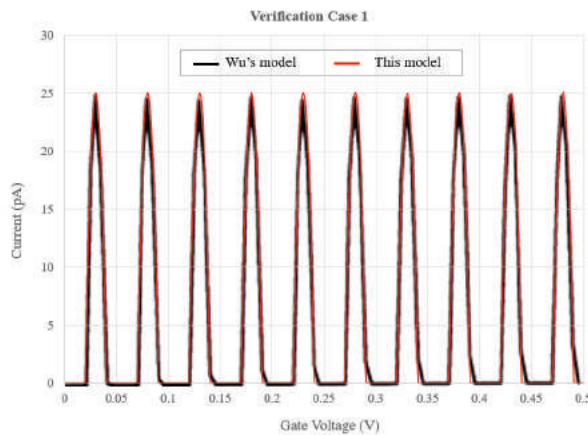


Figure 4.1.

Comparison of Verification Simulation Results for Case 1

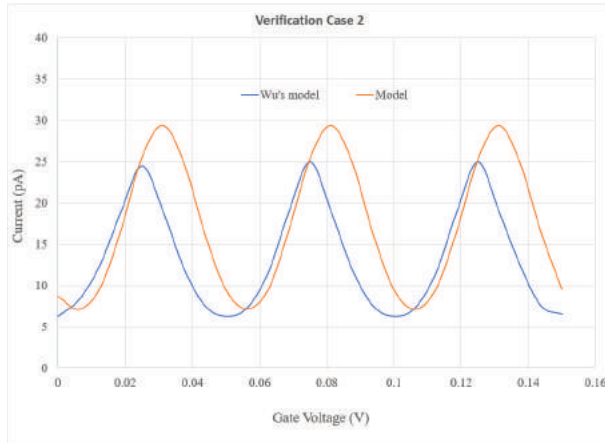


Figure 4.2.
Comparison of Verification Simulation Results for Case 2

5. Device Simulation

The objective for this device simulation is to study the effects of temperature, gate capacitance, tunnel resistances, and source to drain voltage on Coulomb oscillation. Through the study of Coulomb oscillation, the physics and behavior of the single-electron transistor can be better understood. Case 2 from the verification work is chosen as the base case. The parameters used for the four test cases in this section are varied based on this scenario.

5.1 Test Case 1: Temperature

As mentioned previously, the single-electron transistor's operation at room temperature is a major setback in the device's development. For higher temperatures, a minuscule capacitance is necessary to construct a design that can overcome arbitrary tunneling. To examine the case of room temperature, two SET devices are modeled in MATLAB. They share the same values for junction resistances, junction capacitances, gate capacitance, and source-drain voltage, but they vary in temperature. While one device is set at 30 K, the other is set at 300 K (approximately at room temperature) to emphasize the SET's properties at room temperature. Table 5.1 indicates the devices' parameters.

Table 5.1. Parameter Values of SETs Operating at Different Temperatures

	SET 1 (base case)	SET 2
T	30 K	300 K
R_{T1}	100 M Ω	100 M Ω
R_{T2}	100 M Ω	100 M Ω
C_1	1.6 aF	1.6 aF
C_2	1.6 aF	1.6 aF
C_g	3.2 aF	3.2 aF
V_{sd}	0.01 V	0.01 V

5.2 Test Case 2: Gate Capacitance

To analyze the effect of gate capacitance on electron tunneling, three SET devices with different gate capacitance values are modeled in MATLAB. All other values are kept the same for these transistors. See Table 5.2 for the devices' parameters.

Table 5.2. Parameter Values of SETs with Varying Gate Capacitance

	SET 1 (base case)	SET 3	SET 4
T	30 K	30 K	30 K
R_1	100 M Ω	100 M Ω	100 M Ω
R_2	100 M Ω	100 M Ω	100 M Ω
C_1	1.6 aF	1.6 aF	1.6 aF
C_2	1.6 aF	1.6 aF	1.6 aF
C_g	3.2 aF	1.2 aF	5.2 aF
V_{sd}	0.01 V	0.01 V	0.01 V

5.3 Test Case 3: Tunneling Resistance

The impact of tunneling resistance on electron tunneling is studied by modeling 2 SETs with different junction 1 resistance values and 2 SETs with different junction 2 resistance values. As in the previous simulations, these

transistors do not vary in other parameter values. Tables 5.3 and 5.4 provide a summary of the devices' parameters.

Table 5.3. Parameter Values of SETs with Different Junction 1 Resistances

	SET 1 (base case)	SET 5	SET 6
T	30 K	30 K	30 K
R_1	100 MΩ	10 MΩ	200 MΩ
R_2	100 M Ω	100 M Ω	100 M Ω
C_1	1.6 aF	1.6 aF	1.6 aF
C_2	1.6 aF	1.6 aF	1.6 aF
C_g	3.2 aF	3.2 aF	3.2 aF
V_{sd}	0.01 V	0.01 V	0.01 V

Table 5.4. Parameter Values of SETs with Different Junction 2 Resistances

	SET 1 (base case)	SET 6	SET 7
T	30 K	30 K	30 K
R_1	100 M Ω	100 M Ω	100 M Ω
R_2	100 MΩ	10 MΩ	200 MΩ
C_1	1.6 aF	1.6 aF	1.6 aF
C_2	1.6 aF	1.6 aF	1.6 aF
C_g	3.2 aF	3.2 aF	3.2 aF
V_{sd}	0.01 V	0.01 V	0.01 V

5.3 Test Case 4: Source-Drain Voltage

The impact of source-drain voltage on electron tunneling is evaluated by modeling 3 SETs with different V values. As in previous cases, these transistors do not vary in other parameter values. The devices' parameters are listed in Table 5.5.

Table 5.5. Parameter Values of SETs with Different Source-Drain Voltages

	SET 1 (base case)	SET 6	SET 7
T	30 K	30 K	30 K
R ₁	100 MΩ	100 MΩ	100 MΩ
R ₂	100 MΩ	10 MΩ	200 MΩ
C ₁	1.6 aF	1.6 aF	1.6 aF
C ₂	1.6 aF	1.6 aF	1.6 aF
C _g	3.2 aF	3.2 aF	3.2 aF
V _{sd}	0.01 V	0.025 V	0.04 V

6. Results and Analysis

The graphs in this section show the current-gate voltage characteristics in the SET devices modeled in section 5. For the most part, the graphs corroborate the fundamental theories of single-electron transistors: the Coulomb blockade and the Coulomb oscillation. Thus, the results yielded from the model in this research are adequate. Another way the results can be verified is by analyzing the definition of current in physics, which is the amount of charge flowing through an area in a certain time interval ($I = q/t$). As shown on the y-axis on the graphs below, the current is on the magnitude of pA. The charge of an electron is $e = 1.60 \cdot 10^{-19}$ C, and the tunneling interval across the quantum dot for each electron can be assumed to be on the order of nanoseconds. Given these conditions, the current magnitudes produced by the simulation are reasonable.

6.1 Test Case 1: Temperature

The simulation of two identical single-electron transistors operating at different temperatures demonstrates the device's temperature sensitivity. One device is set at 30 K, which is significantly below room temperature. The second device is set at 300 K, which is assumed to be room temperature. Figure 6.1 shows the IV characteristics of a single-electron transistor operating at 30 K. The Coulomb oscillations in the graph are clear, indicating that the transistor functions as expected under this condition. On the other hand, Figure 6.2 shows the IV characteristics of a single-electron transistor operating at 300 K. The model demonstrates that the device does not have clear Coulomb oscillation properties when operating at room temperature,

for the graph does not have sinusoidal characteristics. There is neither a stable amplitude nor a clear period, which suggests that the electron tunneling process is inconsistent and unstable. The high temperature at which the single-electron transistor is operating justifies this factor since the electrons are thermally excited.

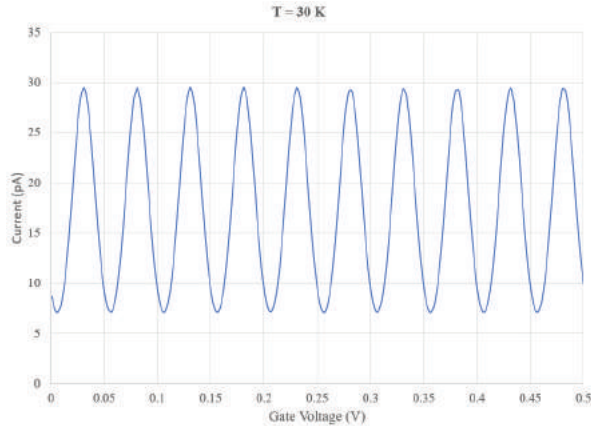


Figure 6.1.
IV Graph at 30 K

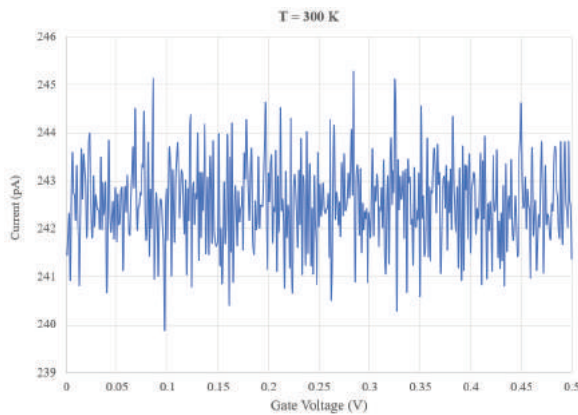


Figure 6.2.
IV Graph at 300 K

6.2 Test Case 2: Gate Capacitance

Another simulation is performed to test the impact of gate capacitance on the single-electron transistor's functionality. Figure 6.3 indicates that the overall current and the amplitude and period of the IV graph decrease with increasing gate capacitance. For the devices with $C_g = 1.2$ aF and $C_g = 5.2$ aF,

the Coulomb-oscillation period is 2.6 times lower and 1.6 times higher than the base case, $C_g = 5.2$ aF, respectively. This result ensures that the MATLAB algorithm models the Coulomb oscillation effect as expected since the period of the Coulomb oscillation is given by $V = e^2 / C$. In fact, the results of this experiment corroborate the findings of Paniz Khanmohammadi Hazaveh, who has also demonstrated in his dissertation that the Coulomb-oscillation frequency is proportional to the gate capacitance [12].

6.3 Test Case 3: Tunneling Resistance

The following simulation is executed to examine the impact of tunneling resistance on a single-electron transistor's electron tunneling and its corresponding IV properties. First, a test is performed on the first junction. One SET is modeled so that $R_{T1} = 10$ M Ω . Another SET is modeled so that $R_{T1} = 200$ M Ω . The ratio for the tunnel resistance values is 1:10:20. However, the ratio for the current values is approximately 10:1.6:1 and is not directly inversely proportional to the resistance. This phenomenon occurs because the tunnel resistance of junction 1 is comparable to that of junction 2 and does not dominantly control the current flow. To study the effect of junction 2 tunnel resistance, tests are performed to two devices with R_{T2} of 10 M Ω and 200 M Ω along with the base case of 100 M Ω . Figure 6.5 shows the current for the 3 SET devices. The ratio for the tunnel resistances is 1:10:20. The ratio for the currents is only approximately 2:1.2:1 and is even lower than that for junction 1. This indicates that junction 2 is not as potent as junction 1 in controlling the source to drain current.

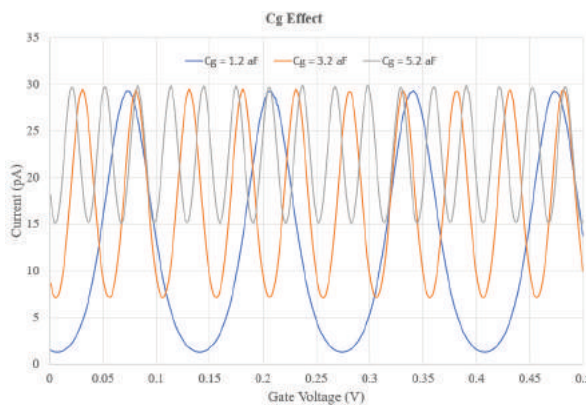


Figure 6.3.

IV Graph with Different Gate Capacitance Values

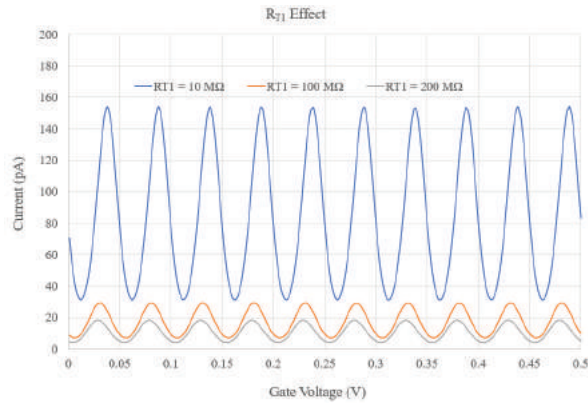


Figure 6.4.
IV Graph with Different R_{T1} Values

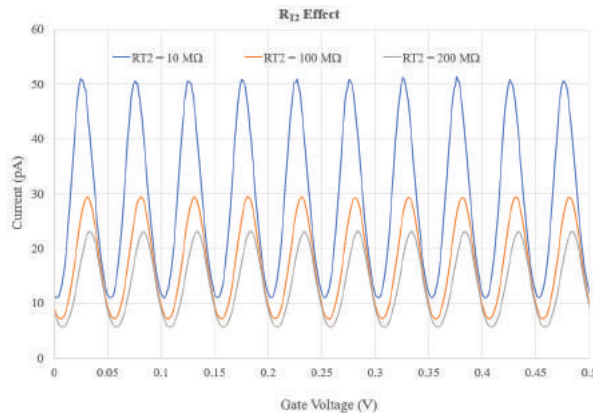


Figure 6.5.
IV Graph with Different R_2 Values

6.4 Test Case 4: Source-Drain Voltage

The final simulation is executed to determine the effect of source-drain voltage on the IV characteristics for single-electron devices. In Figure 6.6, the IV curves of three different devices are plotted. The transistors with $V = 0.01$ and $V = 0.025$ V have clear Coulomb oscillations with similar periods and amplitudes, but the device with $V = 0.04$ V appears to be roughly constant with no Coulomb oscillations. When the source-drain voltage becomes too large, as in the case of $V = 0.04$ V, the misalignment effect of the island's occupied levels and the available levels in the electrode is minimized, leading to the disappearance of Coulomb oscillations.

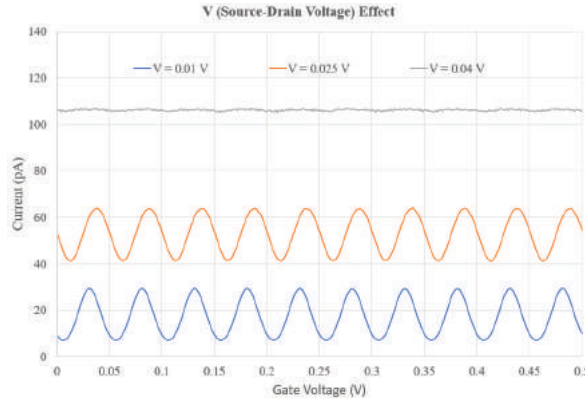


Figure 6.6.
IV Graph with Different V_{sd} Values

All three transistors exhibit a difference in current. The current appears to be directly proportional to the source-drain voltage, which confirms the Coulomb blockade effect in single-electron transistors. As discussed in Section 2.1, a voltage bias is applied to overcome the Coulomb blockade energy. Hence, the larger the voltage, the higher the tunneling rate and the greater the current.

7. Extended Study

Because the simulation of the single-electron transistor in Section 6.1 does not display tunneling features at room temperature, a new model is constructed. Now, a comparison is drawn between the original device at 300 K from Section 6.1 and the new device at 300 K. The new SET model has capacitance values that are reduced by one order of magnitude relative to the original SET. See Table 7.1 for the two devices' parameters.

Table 7.1. Parameter Values of SETs with Different Capacitances at Room Temperature

	SET 1	SET 2
T	300 K	300 K
R_{T1}	100 M Ω	100 M Ω
R_{T2}	100 M Ω	100 M Ω
C_1	1.6 aF	0.16 aF
C_2	1.6 aF	0.16 aF
C_g	3.2 aF	0.32 aF
V_{sd}	0.01 V	0.01 V

By decreasing the capacitances of the single-electron transistor by ten times, the Coulomb oscillation is restored. This outcome is consistent with the theory that charging energy can be increased by reducing the capacitance of the island to overcome the effect of thermal energy. Figure 7.1 shown below is the graph of the transistor's current vs. gate voltage.

8. Conclusion

For the most part, the models developed in this project are consistent with the physics of the single-electron transistor device. The initial results in the temperature-focused simulation verify that the tunneling process of single-electron transistors is more difficult to control at room temperature due to high thermal energy. A revised model is later developed to demonstrate a single-electron transistor that functions as intended at room temperature by decreasing its capacitance values. This modification supports the concept that smaller capacitance values can increase the charging energy as a counterbalance to the high thermal energy. In addition, the IV graph for the gate capacitance study exhibits the Coulomb oscillation effect, for the period is inversely proportional to the gate capacitance. Furthermore, the test on tunneling resistance shows that the first junction is the determining factor for the tunneling rate and current if the resistance of junction 1 is greater than the resistance of junction 2, which correlates to the theory of the Coulomb staircase. Finally, the test on varying source-drain voltage values supports the Coulomb blockade theory.

Despite the overall accuracy of the models, the limitations of these simulations should be considered so that newer, improved models can be created.

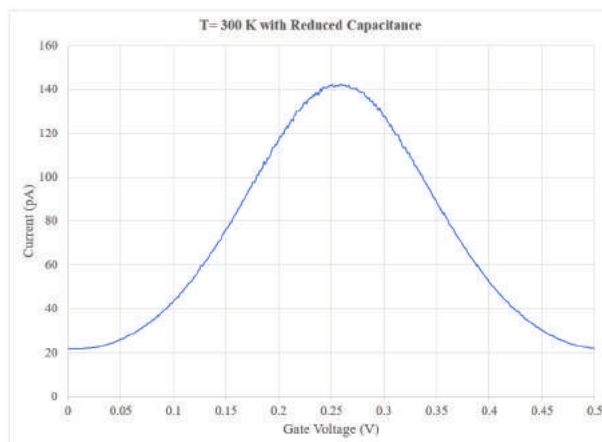


Figure 7.1.

IV Graph at 300 K with Reduced Capacitances

The algorithm developed for this model applies only to metallic single-island SETs because its generalizations are insufficient to model semiconductor SETs. A more complex algorithm can be formulated in the case of semiconductor SETs, whose electron tunneling is easier to control than metallic SETs. Since single-electron transistors must be integrated for potential conventional use, it is also useful to model multi-island SETs, which achieve controllable room temperature operation more easily. Most importantly, parameter values are assumed to be independent values for simplification, whereas the values are actually interdependent. This assumption may affect the accuracy of the models. Instead of selecting arbitrary values in a reasonable range for the transistors, values based on real materials can be tested in future studies, which would yield an enhanced model and lead to a comparison of materials for the island. Nevertheless, this research gives an adequate model for single-electron transistors and establishes a premise for further investigation. The simulation of single-electron transistors can provide insight into device design of single-electron transistors. For single-electron transistors to carry out their purpose in reducing power output in everyday electronic devices, large-scale integration and reduction of fabrication cost should be further explored.

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Appendix

1. MATLAB Program for Monte Carlo Simulation

Main Program

```

% New approach Coulomb oscillation
%Setting parameters
Ec = -1.6022e-19; %Electron charge
Rt1 = 100e6;
Rt2 = 100e6;
T0 = 30;
q0 = 0;
C1 = 1.6e-18;
C2 = 1.6e-18;
Cg = 3.2e-18;
C_total = C1+C2+Cg;
V=.04;
Vg = 0;
Q = 0+q0;
index = 0;
for i = 1:500
resolution = 0.001;
Vg = i*resolution;
time_accumulate = 0;
Count = 0;
Count1 = 0;
Count2 = 0;
Count3 = 0;
Count4 = 0;
for Tu = 1:200000
    for Te = 1:4
        if(Te == 1) %tunneling from 1 to 4
            DE1 = (Ec/C_total)*(0.5*Ec+Q-(Cg+C2)*V+Cg*Vg);
            T_rate1 = Tunnel_rate(DE1, Rt1, T0);
            t1 =-log(rand)/T_rate1;
            T_event = 1;
            Q1 = Q+Ec;
        end

        if(Te == 2) %tunneling from 4 to 1
            DE2 = (Ec/C_total)*(0.5*Ec-Q+(Cg+C2)*V-Cg*Vg);

```

```

        T_rate2 = Tunnel_rate(DE2, Rt1, T0);
        t2 = -log(rand)/T_rate2;
        T_event = 2;
        Q2 = Q-Ec;
    end

    if(Te == 3) %tunneling from 4 to 3
        DE3 = (Ec/C_total)*(0.5*Ec-Q-C1*V-Cg*Vg);
        T_rate3 = Tunnel_rate(DE3, Rt2, T0);
        t3 = -log(rand)/T_rate3;
        T_event = 3;
        Q3 = Q-Ec;
    end

    if(Te == 4) %tunneling from 3 to 4
        DE4 = (Ec/C_total)*(0.5*Ec+Q+C1*V+Cg*Vg);
        T_rate4 = Tunnel_rate(DE4, Rt2, T0);
        t4 = -log(rand)/T_rate4;
        T_event = 4;
        Q4 = Q+Ec;
    end

    Te = Te +1;
end
index_pre = index;
time = [t1 t2 t3 t4];
[min_time index] = min(time);
min_time;
index;
time_accumulate = time_accumulate + min_time;
if(index == 2)
    Count = Count +1;
    Count2 = Count2 + 1;
    Q = Q2;

elseif(index == 1)
    Count1 = Count1 + 1;
    Q = Q1;
elseif(index == 3)
    Count3 = Count3 +1;
    Q = Q3;
else

```

```
        Count4 = Count4 +1;
        Q = Q4;
    end
    Tu = Tu +1;
end
I_ave = (Count*-Ec)/time_accumulate;
Count_data(i) = Count;
Count1_data(i) = Count1;
Count2_data(i) = Count2;
Count3_data(i) = Count3;
Count4_data(i) = Count4;
n_data(i) = Q;
I_data(i) = I_ave;
V_data(i) = Vg;
end
plot(V_data, I_data);
```

2. Function for Tunneling Rate Calculation

```
%Tunneling rate function
function y = Tunnel_rate(FDF, FRT, FT)
FEc = -1.6022e-19; %Electron charge
y = -FDF/(FEc^2*FRT*(1-exp(FDF/(k*FT))));
end
```



Social Media and Its Effects on the Foreign Language Curriculum for Undergraduate University Students

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Abstract

People are able to communicate through common languages. As we progress into a more interconnected world due to the development of technology, having to learn foreign languages is turning into a requirement in the pedagogies of many school curricula. This enables students to enter society with a greater ability to connect with others from various cultural backgrounds. However, many students struggle to learn foreign languages and their associated cultures. This paper aims to evaluate the use of social media to make foreign language education more approachable for students. Exploring the results of research focusing on Computer-Aided Language Learning (CALL) and the language in social media commonly known as “textese”, the paper concludes that the common familiarity of social media, and the advanced development of technology, are benefits that support implementing social media in foreign language learning. Additionally, the globalization of social media offers the advantage of allowing students to have direct interaction with different cultures around the world. However, as the use of “textese” in social media includes various inaccuracies, there are also disadvantages that are particularly detrimental for beginners. Therefore, the results imply that social media is more beneficial when applied in foreign language curricula for advanced learners who can also develop cultural understanding through their education.

Keywords: Social media, Computer-Aided Language Learning, textese, foreign language

1. Introduction

With 57.3% of the world population using the internet in 2019 (Internet World Stats, 2019), the rising significance of technological developments has led to a greater awareness of the various cultures present in our world today. In particular, the use of social media has enhanced this effect through its multiple forms of communication and interaction with others. Social media users can now observe how people with different backgrounds live in their communities and shape their identities based on their culture (Boyd, 2016; Harvey, 2014). Understanding a foreign language is a necessary component of acquiring profound cultural knowledge, as a shared language is the only way people from different cultures can communicate and understand diverse perspectives worldwide (Brown et al., 1953). The connection between social media and language acquisition is getting stronger as the presence of social media becomes more dominant and essential in modern life, especially for the education of young adults (Alshenqeeti, 2018; Reinhardt, 2019).

Education facilitates cultural awareness by connecting people and building relationships. The knowledge helps people understand others' experiences and how they exist within their respective cultures. The perception that university students can help change the world for the better as a result of their education allows them to open up to others, thus building compassion and empathy. Therefore, by providing education to students, especially education related to various cultures, universities can prepare students to enter the wider world better informed about both themselves and others' reality.

2. Purpose Statement

This research project aims to investigate the effect of social media on university students when learning a foreign language. It will explore three research questions:

1. How might models for implementing social media in foreign language curricula impact university students?
2. How does the modern language used in social media affect foreign language learning for university students?
3. How does social media contribute to educating university students about diverse cultures and their respective languages?

3. Definition of Terms

There seems to be a common perspective that the only social media platform that exists are social networking systems such as Facebook, or Twitter, ignoring other areas of social media and their possible influences on various investigations associated with social media (Carr, Sun, Berry, & Harlow, 1993). This is because there is no clear definition of “social media.” One comes from Reinhardt (2019), who refers to social media as “any application or technology in which users participate in, create and share media resources and practices with other users by means of digital networking” (pg. 3). Alshenqeeti (2019) refers to social media as “any site which provides a network of people with a space or a platform to make connections and communicate virtually” (p.60). By combining the general similarities in the definitions, social media will be referred to in this paper as a communication method for user interaction and connection to share their knowledge with other users, creating a major interactive network worldwide. Thus, apart from the primary focus on social networking sites like Facebook, Twitter, and Instagram, my investigation will also include other platforms and resources from the internet, such as, but not limited to, emails, YouTube, and blogs. Expanding the realm of social media to include a wider variety of subject areas allows a more significant investigation on more areas in online education and their differing effects on foreign language curricula.

Regarding the investigation of social media’s influence on modern language, Baron (2008) suggests that there is an international perception “that computers and mobile phones are affecting everyday language and that these effects are generally not for the better” (p. 163). The term “everyday language” is most directly associated with “modern language,” which in this study is defined as an electronically mediated language that portrays the regular communication between users of social media regardless of its formality. For example, abbreviations such as LOL (laugh-out-loud) and ASAP (as soon as possible) are some phrases that can be mentioned when referring to “modern language.”

University students are the primary participants in the studies included in this paper. There is an underlying assumption in these studies that traditional-age undergraduate students, ages 18–22, can be involved in collegiate curricula that provide opportunities for learning foreign languages. This assumption includes the understanding that undergraduate students and secondary high school students represent the students who are the most familiar with using social media.

4. Delimitations of the Study

This paper will consider only those research studies that work under the assumption that all schools, students, and teachers have access to various technologies, such as computers, the internet, and social media sources. However, there are benefits and problems a developing country may face when using social media in academic platforms, such as “the lack of adequate technical infrastructures” (p. 381) in countries including Zambia and Nigeria (Magoi, Aspur & Abrizah, 2017). Reports showed that these countries did not have sufficient knowledge of social media’s benefits for it to be used in academic libraries. Furthermore, social media’s inaccessibility in developing countries can be a barrier for its application in academics. Countries like China will also not be considered in this study as they have banned access to specific social media sites due to political issues (Huang, 2018).

Furthermore, social media will be referred as a platform that presents us with countless opportunities to connect with new people in different circles. As there is no guarantee that cultural interaction occurs between social media users without the assumption illustrated above, studying how cultural exchange can impact foreign language learning can be unseemly since it may not be happening in the first place.

Additionally, although different curricular standards exist for learning each specific language, this study will ignore the dissimilarities and unify them to one general curriculum of foreign language learning. Thus, when talking about “foreign languages,” the paper refers to all languages that are not the native language for an individual, rather than specifying one particular language, since one’s native and foreign language are different depending on one’s nationality.

5. Literature Review—Research Question #1: How might models for implementing social media in foreign language curricula impact university students?

Learning a new language requires time, patience, and persistence. It is not easy for many students. Students can start feeling anxious when they think they are incapable of learning a new language, thus demotivating them to continue their language education (Horwitz & Cope, 1986). Therefore, the profession would benefit from research on effectively teaching students foreign languages so that they remain encouraged, motivated, and empowered to continue learning. One method for creating a useful and engaging language curriculum is implementing social media in the learning process. The

following section will consider different social media areas and how they might benefit students in the language learning process.

5.1 Computer-Assisted Language Learning (CALL)

Several studies on the involvement of technology in foreign language education, including those by Alshenqeeti (2018), Kessler (2018), Muthuram (2018), and Reinhardt (2019), all refer to the term “Computer Assisted Language Learning” (CALL). CALL is the application of technology in foreign language learning, using technological systems and external platforms in online media created to educate users. Although some limitations still exist, CALL’s introduction has been a significant benefit to the foreign language curriculum by enhancing student interaction in lessons. Pinner (2012) discovered this impact through research on language learning beginners who learned a language through the incorporation of CALL in a typical classroom. After taking a placement test to determine their language ability, the participants were given software with various activities to develop speaking, listening, writing, and reading language skills by involving multiple technological features. These included buttons such as the “Exit” button (to leave the program or return to the previous menu), the “Microphone” button (to record the user’s voice for practice), the “Headphone” button (to play back the user’s voice and to compare it with the native speakers’ representations), the “Rewind” button (to go to previous sentences), the “Repeat” button (to repeat the last sentence aurally), the “Pause” button (to let users pause), the “Forward” button (to go to the next sentence), and the “ABC button” (to repeat the previous sentence aurally with accompanying transcription) (p. 194).

The researchers found that the abundance of CALL features were effective in helping the participants answer more questions overall, supporting the claim that CALL benefits students’ education. This is mainly because the extensive development of technology allows users to utilize its functions for various applications, which means that the same feature can be used for different purposes of learning. For example, referring back to Pinner’s study (2012), a student who wants to improve their listening may prefer to use the “Headphone” button as it provides an aural learning platform. Similarly, a student who wants to work on their speaking skills, or studies better by practicing speaking rather than writing, may use the “Headphone” button more often to apply their learning style through the technology provided to enhance this skill. Hence, students can benefit from CALL by using the most suitable method for their individual learning.

However, as social media is a relatively recent phenomenon, there is only limited research on how CALL is applied in education, raising the question

about how social media contributes explicitly to the pedagogies in the foreign language learning curriculum.

5.2. Social Media in Classroom Settings

Social media involves technological features that enable students to develop an array of skills, including speaking, writing, listening, and reading, within a language curriculum.

Faizi, Afia & Chiheb (2014) conducted a survey “to examine students’ perceptions and attitudes about using social media for learning foreign languages” (p. 65) and found that, out of 720 university students who were questioned, around 570 (81%) use social media as a method of learning a foreign language. Furthermore, among the different platforms that social media offers, about 67% and 61% of the students would use social networks and media sharing sites. In contrast, none of the students used language-learning specified technologies to develop their skills. The data indicate how students use the social media platforms that they are most familiar with and use regularly outside the education realm, rather than using those specified for curricular language instruction purposes. Based on this conclusion, teachers are advised to use social media platforms, such as Facebook and YouTube, to motivate students to learn a language. These are the most commonly used social media sites globally, having 85% and 79% of Internet users respectively (Ahmad, 2019), and would encourage more students to use them to contribute to their learning.

Also supporting Faizi, Afia & Chiheb is Kessler’s research (2009) on the impact of using wiki sources to enhance English writing skills for non-native English students. A wiki is a social media platform that consists of “any online database or website which permits a community of users to edit and add content” (Chandler & Munday, 2016; p.90). Therefore, wikis can assist learning by having students edit each other’s work freely on a topic they study. Students were required to produce a wiki page on a topic they learned in class together, having to peer assess each other’s writing without any teacher intervention. For their wiki page to remain useful and accurate, the students had to take responsibility and act upon the task themselves to continually look for errors and mistakes in their page. The study results showed that although the students were confident and content to find multiple errors in the text accurately, they were still reluctant to make edits on minor mistakes that did not influence the text’s meaning, thinking they were insignificant. This study concluded that when social media platforms, such as wikis, are used for educational purposes rather than interaction and communication, students feel forced to use them in ways that are either undesirable or unfamiliar, losing motivation.

5.3 Benefits of Social Media in Foreign Language Curricula

Faizi, Afa & Chiheb (2014)'s investigation of social media's impact on foreign language learning found that the foremost advantage of employing social media in the curriculum is the opportunity for students to experience communicating with native speakers. This interaction allows students to have a distinct familiarity with the language and its speakers compared to the limited, uninteresting, and "confined" conversations created in classrooms. Such opportunities illustrate how the various social media resources, starting from social networking sites that allow global communication to broadcast sites that expose students to how the language is spoken regularly, are useful methods for students' education. This revelation for the student not only assists in learning the language itself but also develops a cultural understanding for the student by directly communicating with people from other cultures about varying perspectives. This is significant in foreign language learning as there is an "assertion that foreign languages are not only useful but necessary for an understanding of other peoples and other cultures," according to Brown et al. (1953).

Results from research studies imply that services provided by various social media platforms are helpful for students who are learning a foreign language as they help the students develop multiple skills, such as speaking, listening, reading, and writing. Additionally, these platforms also help one build character, such as enhancing self-esteem or gaining an awareness of different cultures worldwide (Alshenqeeti, 2018; Faizi, Afa & Chiheb, 2014), meaning that social media can be instrumental in the foreign language curricula. A survey carried out by Horwitz, Horwitz & Cope (1986) suggests that a student learning a foreign language would likely be fearful if learning the language causes anxiety and confusion. The review of different features of social media impacting Polish foreign language students identifies that the particular skills and self-growth acquired by utilizing social media in learning can reduce the fear of a student learning a foreign language, and further help them become proficient in applying the language in their regular life by advancing their communication abilities (Prizel-Kania, 2015). Therefore, the various social media platforms can help individual students acquire different skills by providing the opportunity to develop language skills in diverse ways (Faizi, Afa & Chiheb, 2014).

5.4 Problems of Social Media in Foreign Language Curricula

Although it has clearly been shown that social media can be applied in foreign language curricula for enhancing the education process for students,

problems may arise when utilizing social media. Knight & Rochen (2012), for example, examined the results of the Start Online project held in 2010, which was an attempt to implement social media in a pre-session program for new students at Bucks New University in order to improve the transitioning process the students had to face before their actual academic year started. The findings showed that when social media platforms were used for their intended purpose of developing social skills and interacting with other students, they were used extremely effectively. However, when social media platforms attempted to become involved in academic activities directly related to the students' education, there was a significant downfall in the number of participants who were willing to engage in the study, and in interest for the process.

Similar outcomes came from Saha & Guha (2019)'s study on the general use of social media by university students in Bangladesh, and that of Fewkes & McCabe (2012), which specifically focuses on the impact of Facebook as a learning tool for students. With around 85% of the 502 students acknowledging that social media affects their life in some way, only 15% of the students in Saha & Guha's survey responded that they have used social media for educational purposes. Additionally, the students for the latter study gave a similar response. The most uncommon use of Facebook was for their education, and using Facebook in classrooms was not supported by their school.

It can be concluded from the results of these studies that although the familiarity of social media can benefit a student's learning, this feature can distract, or even discourage them, by applying educational purposes to something that students would prefer to use for enjoyment and entertainment. This analysis is associated most directly with foreign language learning students, as Faizi, Afia & Chiheb (2014) stated: "it has been observed that though there are social online communities, such as Livemocha and Busuu, which are dedicated to language learning, none of the respondents seems to be using them." Thus, students are not directly motivated to learn just by including social media into their curriculum. Furthermore, it is emphasized that social media is a platform which users use regularly for entertainment and relaxation during their free time rather than for purposes for attentive tasks such as education.

5.5 Pedagogical Implications

It is necessary for teachers to start using social media platforms in their teaching methods as we are living in an era of technological progress that is changing student learning proficiencies (Alshenqeeti, 2019). This can be effectively done by observing positive and negative impacts that different

platforms of social media have on different situations. This could help teachers implement strategies depending on the learning objectives they set for their curriculum (Fewkes & McCabe, 2012; Reinhardt, 2019).

Changing current curricula using combinations of different social media in education has proven to provide a personalized learning experience for students, enhancing their learning by giving the students more control in their education. The learning pedagogy in which students are given agency in their learning is particularly important in a foreign language curriculum, since students acquiring knowledge in this field can feel anxious if they continue to face barriers that demotivate them to continue learning (Horwitz & Cope, 1986). A CALL course causes students to take responsibility for their learning through collaborating with other students and communicating with them in the process. Students become more active when participating more directly without the presence of a teacher who only gives them information without further contribution by the student in the learning process. However, it is still necessary for teachers to be a part of the learning process. Knowledge of the content of the curricula is required, as is competency in the technology and social media platforms being used. An understanding of the benefits and drawbacks that the different components can provide for the students in order to support those who struggle to use CALL technology (Muthuram & Pushpalatha, 2018) is also advised for teachers in this field. Therefore, a successful foreign language classroom would be one that enhances active learning by students through using social media platforms as a tool that is supported by teachers, and to do so successfully requires a great contribution by both the students and teachers.

6. Literature Review—Research Question #2: How does modern language used in social media affect foreign language learning for university students?

Baron (2008—2010), when he considered the principles of education, stated that “as children, we naturally absorb the spoken language of our environs . . . schools then further shape the way we speak—and write” (p. 169). Essentially, this means that the interactions a student has with his or her community influences the knowledge they obtain in their education; as this interaction increases, the more influence it has on the student. In 2018 and 2019, there has been an increase of 288 million, and an increase to 367 million active social media and internet users respectively (WeAreSocial, 2019). This indicates how, based on Baron’s theory, students learning a language would be greatly affected by the language used in social media. This “modern language” has become associated with their environment and community. Therefore, it is

necessary to evaluate the modern language used in social media to identify whether social media is an effective platform which benefits or blemishes the foreign language learning process for university students.

6.1. Electronically Mediated Communication

Another term used to describe communication using technology is Electronically-Mediated Communication (EMC). There are various features of EMC that influence future developments of the English language (Baron, 2009). Emails, blogs, text messaging and instant messaging are examples of some of the social media platforms that are regularly associated with technology and communication (Baron & Ling, 2011).

Before the discovery of electronic communication, people were more accustomed to having face-to-face, direct conversations than communicating from different locations (Chun, Smith & Kern, 2016). Face-to-face communication is now being reduced and replaced by the growing utilization of EMC (Pierce, 2009), and this form of communication is what allows people to converse globally and singly.

However, Electronically-Mediated Communication can also cause misunderstandings when sharing information. Research by Chun, Smith and Kern (2016) describes how EMC allows both simultaneous and non-simultaneous conversation that can cause issues when the messages shared by the users are not necessarily received until much later. Researchers indicate how the gap in the timeframe from when the sender shares information, and when the recipient uses the information for their own understanding, can cause the meaning of the actual knowledge shared in the conversation to change. In support of this notion, Baron (2008—2010) stated, “Yesterday’s change is today’s norm” (p. 161). Clark (1999) defines this circumstance as “disembodied-language,” and it is particularly crucial to acknowledge this feature of EMC to avoid this chance of miscommunication. Teachers have to be aware of how to prevent misinterpretation of the information received by a student during their learning.

Baron (2008—2010) signifies three ways in which EMC can impact students’ learning of language:

1. EMC has “created a whole new language (p.162);”
2. Language is debased when created by technology;
3. Traditional language is harmed due to EMC.

Each of these elements will be investigated later in this section of the paper.

6.2 Language Inaccuracy

People are becoming busier by the day, causing a greater proclivity for processes that are less time consuming and tiring, even in writing (Baron, 2008—2010). This notion is supported by Whiting & Williams' (2013) investigation on why people regularly use social media. After interviewing 25 people, between ages 18 and 56, on the application and reasons for using social media, the two researchers characterized the participants' responses into ten main themes. With 56% of the respondents acknowledging "convenience utility" as a reason, it can be seen that the fairly easy accessibility and availability of social media, as well as the ability to multitask, is a crucial reason for social media to attract more users and initiate greater global communication. While communication has become more rapid by using social media, users' writing can also be done more carelessly as they are reluctant to check whether or not the language they are using is correct, As long as the meaning is correctly shared. However, these inaccuracies in the structure of the language in social media may affect users who are using social media to learn a new language. When students learn a new language via social media, they may miss the opportunity to learn the language's formal structures and vocabulary.

6.3 Textese

Features of the language in text messages are commonly referred to as "textese," or "textism," in miscellaneous papers that investigate electronically mediated communication platforms (Crystal, 2009; Grace et al., 2013; Kemp. et al., 2014; Van et al., 2016). "Textism" is essentially the abbreviation of words or phrases in the language (e.g., "LOL" meaning "laugh out loud"). According to Dixon (2011), the reason for creating these ubiquitous abbreviations was due to the limitations on the number of characters that social media platforms have when sharing messages. In order to fulfil "the need to get a point over quickly, there developed the need to use as few words and letters as possible to get one's point across" (p. 30).

However, as the popularity of technology-based communication is growing and more "textese" language is being used by social media users, there is a growing concern regarding the relationship between the use of textism by students and their literacy skills, which include the ability to use the correct grammar, spelling, and punctuation when using the English language (Baron & Ling, 2011).

6.4 Grammar

Kemp et al. (2014)'s study that investigated the effect of "textese" on students' grammatical skills demonstrated that, although it may not be directly significant, text messaging with grammatical errors does impact a student's knowledge of the grammatical context of the language. The study consisted of students from primary school through university, who were comfortable with using English while communicating. The researchers recorded the participants' text messages that they had sent within a two-day period, and then converted the "textese" into conventional English grammar structures that the students perceived as being correct. The grammatical errors were then analysed by the researchers.

Additionally, Kemp et al. directly investigated the students' grammatical skills by having some take the "Test of Receptive Grammar II" assessment, and others take the "Grammatical Spelling Choice Task." Each assessment had students identify the correct grammatical structure in sentences in a given text. Finally, primary data were collected in the study by having students respond to a questionnaire based on their regular use of technology and text-messaging.

By analysing multiple sources of data, the researchers concluded that textisms were commonly used among all age groups. 20% of the textisms used by university students were non-grammatical, with most errors being missed capital letters and punctuation or words that were additional function words that are not needed to understand the content of the message being sent. Finally, although there was evidence that the students could identify grammatical errors in sentences, the study showed that they were not always accurately corrected, or even identified in the first place.

Supporting these results is a study by Cingel and Sundar (2012), who similarly carried out a survey for middle school students in the United States, on their behaviour when text messaging. They used data from a grammar assessment that students were already required to take at the end of grade nine. The purpose of the assessment was to identify the grammatical skills of the students. The researchers compared the assessment scores and the survey data which indicated individual students' text messaging platforms. The relationship between texting platforms and grammar proficiency suggests that "most adolescents encounter a sizeable number of grammatical adaptations while text messaging on a daily basis" (p.1315). This seems like a negative relationship, because the students will ultimately learn non-traditional (i.e., inaccurate) grammar, a phenomenon explored in the next section of this paper.

6.5 Spelling

Textism also contains various features that help change the language to make them suitable in informal settings by changing words or phrases into shorter symbols, simplifying the original text. Such features include pictograms and logograms, initialisms, omitted letters, nonstandard spellings and shortenings (Crystal, 2009), suggesting that it is important to investigate the impact of the language of social media on standard language. Specifically, the study focuses on spelling, as multiple abbreviations in textism cause users to replace the original language for their convenience in communication.

Mitton (1987) analysed a series of errors in a collection of written texts by secondary school students referring to the topic “Memories of my primary school” (p.495). The spelling errors made by the students were identified by a spelling checker software that discovers misspelled words in texts by comparing the words with ones in the dictionary. Among the errors discovered in the study, the most common were real-word errors, “where some other word was written in place of the right one” (p. 497); this accounts for around 40% of all the errors. In fact, most of the wrong-word errors occurred when writing function words by replacing the necessary function word with a different one. What is particularly important about this finding is the interpretation that social media users do not regularly use function words in their writing as these words are words “whose primary purpose is to contribute to the syntax rather than the meaning of the sentence” (Function Word, 2017). It is possible to infer from the result that the relatively low familiarity with function words and how to accurately spell them results in student users having less understanding of how to actually apply the words themselves.

6.6 Punctuation

As electronically mediated communication platforms represent spoken language rather than written text, punctuation patterns in text messages have been investigated to discover how they can be used to express the conversational tone users want, and how this punctuation has errors when being used for this purpose. For example, Houghton, Upadhyay & Klin (2016) carried out three experiments based on how punctuation can be used to portray different atmospheres through text. The results of all three experiments signified how using a period after a single-word answer to a question represents a more serious and negative mood of the sender for all positive, ambiguous, and negative responses.

Similarly, Baron & Ling (2009) had 22 female undergraduate students at a public university in the American Midwest record the text messages they had sent in a single day. The researchers then analysed the given text message samples, most specifically the punctuation used by the users. An unusually high number of ellipses in the sample texts led Baron & Ling to investigate how the ellipses were being used, and it was eventually identified that “ellipses are sometimes used to indicate speech trailing off . . . for dramatic effect . . . or to separate sentences in lieu of a more standard period (p.60).” Additionally, the investigation of exclamation marks and emoticons showed how they could be used to diminish the effect of periods expressing a brusque tone by “softening or adding emotion to messages” (p. 61). The conclusion derived from this finding is that as punctuation is used in textese for demonstrating particular features of speech rather than adhering to their conventional use of ending sentences or statements, the way they are used is informal and inaccurate grammatically.

Furthermore, among all the messages sent by the students, a significant number (61%) of texts had no punctuation at all, once again supporting the idea that textese goes against the conventional rules of the English language, even if text messages are a representation of written language.

6.7 Linguistic errors in social media for Foreign Language Education

The negative relationship between the use of inaccurate language in social media, mostly in textism, and users’ ability to use the language in a linguistically correct way, helps demonstrate how social media platforms impact students, particularly when they are learning the new language through this application. Referring to Baron & Ling (2009)’s conclusion that indicates that adolescents may be able to learn writing skills through an electronic medium, the results of the studies mentioned in this literature review signify how informal language in social media influences the linguistic abilities of student users by making them too familiar with examples where language is used incorrectly for simplicity. Although this also affects regular social media users, it can be further inferred that foreign users who are unfamiliar with the language are most affected. Foreigners are not aware of whether the language is simplified and used in an informal way for convenience, or if the text portrayed reflects the conventional rules of the specific language. The imprecise boundary of the two situations is detrimental for foreign language learners as incorrect knowledge is being shared with the students, resulting in an improper language education system. Furthermore, it is necessary for users who are learning languages through social media platforms, including textism, to have an awareness of the possible inaccuracies in the language

they are communicating in, so that they can determine whether they will continue using the platform for cultural knowledge acquisition, or find a more suitable method for learning.

However, even if the actual language the students write may have errors, it is shown by Grace et al.'s study (2013) that these mistakes are not made intentionally, as they are still able to detect when it is appropriate to use textism. The corresponding study resulted in two findings. The first study was based on a questionnaire that asked undergraduate students when it is suitable to use textism in various settings such as when writing emails to a friend, or submitting a final paper to a university professor. The results indicated that students recognized textism as appropriate in "informal" settings, particularly in social settings, compared to those in conventional environments and situations. In particular, it was viewed that it was completely inappropriate for students to be using textism in exams, leading to the study's second finding of discovering how textism interacted with formal written exams.

The second finding showed that only 0.02% of the words in the exams had textism. This means that although there were common mistakes of missing capital letters, or apostrophes in the writing to create suspicion of the impact of textism on the English language, its scantiness allowed researchers to view the effect as negligible. In particular, the environments in which the students took the exam were external factors that could possibly have affected the students' performance, allowing this paper to make an assumption that the mistakes made in the texts may be insignificant.

In contrast, the same students reflected the behaviour of using textism in their emails: "It is clear that even students who used textisms in their emails were quite able to avoid using textisms in their formal written exams" (p. 802). Thus, the study supports the finding that there is a close relationship between the regular use of social media and a user's language acquisition, since the errors made are not intentionally done for convenient communication, but are actual mistakes caused by flaws in the user's knowledge of the language.

7. Literature Review—Research Question #3: How does social media contribute to educating university students about diverse cultures and their respective languages?

The function of social media allowing international communication and interaction guides users to naturally learn about various cultures, especially since the barrier between those with differing cultural backgrounds and

experiences can be broken down by using social media (Matthews, 1997; p. 123). Many educational philosophers emphasize the importance of associating a student's education to their cultural background as students become personally involved with diverse experiences, supporting the process of acquiring knowledge (Brooks & Kempe, 2014; Dewey, 1916; Ladson-Billings, 1995). Hence, it can be seen that understanding the diversity in cultural knowledge is a fundamental bridge when connecting social media and education. An individual can learn through the cultural experiences that are taught and enhanced through using social media.

Furthermore, it has been identified that there is a strong interrelationship specifically between one's cultural experience and acquisition of a new language. The Sapir-Whorf hypothesis states that language influences one's thinking ability and as a consequence, the language we speak shapes our culture and background (Buchanan, 2018; Wolff & Hølems, 2011). However, Lev Vygotsky opposed this perspective, stating that it is actually the cultural background and personal experiences that guide students to learning a new language. Due to this change in the beliefs of the cause and effect of language learning for cultural enrichment, the last research question aims to investigate how social media may contribute to clarifying the indefinite relationship between language, culture and education. By understanding educational philosophies and pedagogies that social media may be involved in, it is possible for foreign language teachers to determine whether social media is an efficient platform to depend on for their student's learning, and how it can be utilized most effectively in order to do so.

7.1 Education and Culture

Among the many different viewpoints on education by various educational philosophers, John Dewey, well known as the "father of progressive education" (Westbrook, 1991; p. 502), emphasized education as a social process. From his perspective, for a student to acquire knowledge efficiently, it is necessary to focus on the experiences they encounter during the interactions they have through this social life. The direct involvement of the student during these experiences causes them to develop questions based on their understanding of the process, and through this inquiry, the student further creates "ideas" to think of a solution to the problem they first identified (Dewey & Small, 1897; Dewey, 1916). Therefore, it is possible to associate Dewey's perspective of a successful education system with the necessity of a student understanding a specific culture of their own, as the experiences a human face are dependent on their social and cultural background, and it is this personal experience that enhances their knowledge.

Therefore, it can be inferred that the reason why there are different preferences in what students want to learn is due to each individual coming from different backgrounds, leading to contrasting experiences that provide distinct knowledge based on the perspectives which arise from the experiences.

Similarly, the notion that culture, personal experience, and engagement are crucial for an effective education is also supported by “Culturally-relevant pedagogy”. This principle is based on the idea that the most effective learning process for a student is one that is self-initiated, engaging in their own education by relating the content with their personal experience (Billings, 1995). The pedagogy described by Ladison Billings was carried out from an analysis of why Native American children were underperforming in schools compared to those from other backgrounds, and the main reason for this result had been due to the students being unable to engage with the information being taught as the Native American children were being taught by teachers who mostly had white, middle-class backgrounds (Lynn Brusnahan, 2018). It was identified that the problem had been because of the failure to apply the pedagogy that states that a student is empowered intellectually and socially only through the application of their cultural elements into the curriculum they are learning from. In particular, “Cultural Competence” is a principal pedagogy among the three elements for quality student education. It is massively involved in understanding diverse cultural backgrounds by guiding students to be well informed multiculturally at the end of the curriculum. Through the development of their knowledge of their own culture, students can further utilize this knowledge for understanding material from other backgrounds as well.

7.2 Constructivism

The emphasis on culture and personal experience to engage a student in their education by both Dewey (1916) and Billings (1995) come from the educational philosophy of constructivism. The fundamental principle of a Constructivist’s philosophy is that students, being observers of their personal experience, construct their own realities and perspectives which lead to the diversity in the learning processes of students. Constructivists are attentive towards the enhancement of cultural knowledge as “it is by now a well-established conviction among most of its exponents that constructivism cannot be radical or methodologically consistent without broadly taking into consideration the cultural contexts always implied in the human production or construction of realities” (Hickman, Neubert & Reich, 2009; p.163). Furthermore, the similarities identified from John Dewey’s ideal way

of teaching, and that of a Constructivist's, emphasize how communication and language are fundamental for a student's education, since it is the communication and observation that bring about the different experiences and ideas an individual acquires. (Dewey & Small, 1897).

7.3 Language and Culture

Previously, the Sapir-Whorf hypothesis, also known as "Linguistic relativity," had been accepted in society, leading to the perspective that language influences our thinking, and furthermore shapes our culture (Buchanan, 2018). However, this hypothesis meant that those who speak different languages are unable to interact at all due to language acting as a barrier for people to communicate with others.

Among the various theories that have been raised disputing the hypothesis, Lev Vygotsky's theory of language and culture significance is one that has had a great impact against the Sapir-Whorf hypothesis, and bolsters additional theories by researchers including Jerome Bruner, Michael Cole, Barbara Rogoff, who have been extremely involved in ideas related to culture, communication, and thinking as well (Sawyer & Stetsenko, 2018). His theory was that the social life of individuals, involving the cultural experiences one acquires along with other activities and interactions, influences the process of formulating communication tools, which results in the creation of languages. Thus, his theory states that the language used for communication depends on one's personal experience and the thoughts and ideas from this interaction, rather than the Sapir-Whorf hypothesis, which posits the opposite. Vygotsky's perspective is that language, as one of the most impactful features for formulating our surrounding environment and individual perspectives (Brain Mass, n.d; Cherry, 2019), is significant for the development of an individual and formulation of thoughts. Furthermore, the emphasis on how one's cultural background and experiences influence the learning of a language portrays that Vygotsky is a Constructivist who emphasizes "importance of activity and learning in the process of doing" (Goodman & Goodman, 1990; p. 229).

7.4 Pragmatic Pedagogical Implications

Through the analysis that Dewey, Billings, and Vygotsky all adhere to a Constructivist's perspective, which is the dominant stance of an effective education especially for language learning, there is an indication that the cultural backgrounds of an individual have to be thoroughly evaluated. Therefore, before concentrating on how social media interacts with the

cultural knowledge of an individual, it is important to identify what roles the teacher and students in a classroom for foreign language education play according to a Constructivist's position.

As a Constructivist values the experience of a student as a crucial element of education, the role of the teacher is to make sure that their curriculum provides the opportunity for students to engage with their experiences and further evaluate them themselves. Therefore, a teacher's role in the classroom is not to actually feed the students with knowledge, but instead, be the learners themselves by listening and guiding the students to figure out their own solution (Dewey, 1916). This emphasis on a "learner agency," where the students are in charge of their learning, is influential in educating students about various cultures. Ladson Billings (2018), referring back to her theory of "Culturally relevant pedagogy" and the influence of teachers in classrooms, states that "rather than the voice of one authority, meaning is made as a product of dialogue between and among individuals," indicating how communication is necessary for students to acquire knowledge of various cultures. This can be done effectively when teachers adhere to the role of being a listener as the students attempt to communicate.

7.5 Learner Agency in a Foreign Language Curriculum

Assuming that "learner agency" is the most effective setting for educating students, it is possible to reflect on how a language learning classroom, in particular, can utilize this system. Although the curriculum is "Student-Based", it is still necessary to assist the student. Baron (2011), appraising Vygotsky's perspective of independent learning, states that one of the most critical factors needed for effective education is the "presence of someone with the knowledge and skills to guide the learner", especially since a foreign language is a study with knowledge that a student would not be able to obtain by themselves without guidance to identify if the information they are acquiring is accurate. Additionally, Dewey's statement that a teacher does not only guide the student to the acquisition of knowledge, but also towards reality and the creation of a social life preparing for the future, particularly relates to a foreign language learning setting as social life is only present when communication occurs. This communication is bolstered by languages where the opposing person are the partners who help a child develop their communication skills and language (Dewey, 1916; Goodman & Goodman, 1990).

7.6 Language, Culture, and Social Media

To accomplish the objective of this study, to understand how social media can be incorporated to enhance the learning process of a student, it is necessary to first obtain knowledge of the connection between education and culture, especially for a foreign language program.

From the identification that one's cultural background and knowledge is involved when learning a foreign language, it is possible to determine that by enhancing the cultural knowledge and awareness of diverse backgrounds of the individual, they would be able to receive a more efficient education based on the curriculum. We can thus claim that social media is the most applicable system for this purpose, as a study to identify how knowledge is affected by cultural differences showed results that social media, by breaking the barriers of cultural differences, is able to mediate this issue (Ray, 2013). It was identified that the various platforms in social media, including blogs, wikis, Twitter, and the like each enhance communication between users to allow cultural exchange.

Also, for education as a whole, the setting of equipping the student with personal experience for effective education is easily provided by utilizing social media due to its familiarity for the users. Depending on a user's interest, the behaviours and interactions they have are significantly different (Kim et al., 2014). For example, once again looking at the survey results by Saha & Guha (2019), the vast number of reasons for using social media indicates how the particular uses and resulting outcomes of social media are all different for each individual depending on the purpose.

Therefore, it is possible to conclude that because social media provides the ideal setting of an engaging classroom according to Constructivist thought, and how this also adheres to the development of cultural knowledge, which is essential for learning a foreign language, its contribution to education and cultural understanding of a student is significant and should be utilized more often due to the benefits provided when incorporating the platform in a foreign language curriculum.

8. Findings

Through considering the three research questions by reviewing various studies carried out by multiple researchers, this study was able to identify how social media can contribute to education systems and most specifically foreign language curricula. Moreover, by understanding how it is involved in such processes, it was possible to further investigate on how its contribution can be both beneficial and harmful for a student.

Among the benefits that technology provides in terms of efficiency, it was seen that its applications in classrooms, most particularly in a foreign language learning curriculum, enhanced communication and contribution by students as it involved them using platforms that they were most comfortable and familiar with. Additionally, various applications in social media systems allowed participants in studies to interact with those across the whole world, significant for foreign language learning students as they are able to obtain the first-hand experience of communicating with native speakers who are the most knowledgeable and competent in utilizing the specific language. Furthermore, this benefit of sharing knowledge provided by multiple platforms in social media is an advantage that is useful for modern students as they are already familiar with the skills required to use modern technology, and communication methods that enhance their engagement when using the system.

However, there is a problem with immediately assuming that students will take advantage of the opportunities social media provides for their education, as the studies mentioned above indicate how this is not necessarily true. Rather, instead of social media influencing students to motivate their learning, the opposite effect has been portrayed. The thought of having to learn even through systems that students enjoy regularly in their daily life when relaxing makes them more indolent and reduces the use of social media for such processes.

The second research question, which considers the language users of social media utilize regularly called “Textese,” reveals that a further flaw in using social media for learning a new language is the fact that it is defective when portraying the rules of the conventional language. As social media is a communicative system to make people’s lives much more efficient and productive, people have found ways to simplify the language so that even though there are terminological inexactitudes in the text, the content of the message is still shared. Therefore, the impreciseness in language features such as grammar, spelling and punctuation that “textese” accommodates causes students to be attuned to the error-full social language, and further influences them to reflect the errors when using the language in a formal setting. More significantly for foreign language students is the fact that they are unable to identify when the language is a form of “textese,” and when it is the traditional language, as they do not have any knowledge of its conventional structure, which makes social media a platform which does indeed educate students, but not necessarily with correct information.

Finally, the study shows that there is a strong connection between how students could use both social media and education of a foreign language to enhance their cultural understanding. The final research question augments

the study's focus by discussing how enhancing knowledge through affiliation with a cultural understanding benefits student by making them more engaged and interactive in their learning. As social media is both engaging and interactive, teachers can benefit from using social media in their curriculum to teach their students both the language of a foreign country and also the cultural background of the country. This is acknowledged to be one of the key standards for foreign language curricula universally as we progress to becoming a more interconnected world.

9. Implications

As there are both very significant benefits and consequences associated with using social media for students learning a new language, it is necessary for careful consideration by foreign language teachers to determine whether their students would be able to take advantage of the opportunities social media provides for their education, or whether it would actually diminish the quality of the education.

The most basic, factor to consider is whether the students are competent in using modern technology and social media to implement its use in the curriculum. The advantage of social media identified by the study is its familiarity, since it is assumed that most students regularly use social media in their daily life. If, as a matter of fact, there are students who are inept with this system, they may instead struggle even more when learning through this process, as they are not only unable to learn the actual language by not being able to communicate, but also feel incapable of using such modern systems compared to others. For this reason, it is also important for teachers to be aware of their capacity for using social media as when there is a technological issue, or a student who needs assistance in using the system, the first person students would proceed to for guidance is their teacher, and so the teachers should be prepared and able to adapt to the situations they face for supporting their students.

Secondly, as there are problems which have been identified by using social media platforms to teach a foreign language, teachers should next consider whether or not they would be able to adapt their curricula to diminish the impact so that it does not cause any hurdles. Most important, they should make sure that the resources students use online ideally are not influenced by textese or, if included, students are aware of which phrases are a part of textese so that they understand how both the conventional form of the text and the modern form are incorporated into real life use.

Finally, it is most important to acknowledge that social media is a powerful platform to assist foreign language learners to develop a better cultural

understanding and utility of the language in various cultural backgrounds rather than the language itself, especially since there are multiple inaccuracies in social media text which can teach the students wrong language structures and features. This leads to a premise that rather than being used in foreign language education as a whole, social media is more effective for education of foreign language learners who are already quite experienced with using the language, and are moving to a more advanced curriculum where they start emphasizing the cultural aspects of language learning as well. For beginners, rather than using social media, it is advised that teachers follow the conventional teaching method of a foreign language by teaching the basic grammatical rules of the language. After the students have more knowledge of the basic phrases and can understand the language in more depth, applying social media to the education process is then useful and effective for learning. Further research could focus on the possible impacts social media has on advanced language learners, and whether there are any differences in the overall outcome of the teaching effectiveness for understanding in what circumstances social media is useful and suitable to use.

10. Conclusion

The findings from this research paper showed that the progressive increase in the development of technology and social media have led to its application in various fields around the world, including education. It has been identified that currently, through its involvement in educating users, social media can provide both benefits and problems, particularly for foreign language learning students. Through developing an understanding of the diverging impacts social media can have on one's knowledge, the study provides the opportunity for readers to reflect on their regular use of social media and more specifically, the "textese" they are associated with when uploading photos, making comments, or even liking a specific post, as the language and cultural context of these features can directly impact other users and the acquisition of their knowledge. Noticing how social media is a two-way communication platform so that both users are learning about each other's culture, the study allowed us to recognize how users are then both students, by strengthening the knowledge of another's culture, and teachers, helping others gain the knowledge of the user's own culture.

Having an awareness of the interactions on social media to help enhance knowledge of different cultures, and that social media is a platform which has multiple features depending on the purpose of its use, allows teachers to prepare for activities which are extremely diverse and distinct for both the specified class of students, and the objective of the lesson. While it may be

difficult to immediately determine how to take advantage of social media so that its problems are not reflected in educating students, it is important to acknowledge that the contribution of technology and social media is only growing in society, and so attempts to utilize these platforms in curricula are necessary for long-term development in foreign language education.

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A Blended Culture

Greater Houston Area's Native American Children's Contest Powwow

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Abstract

No two Native American communities are the same, but most of them value passing on their musical and cultural traditions to the next generation (Hoefnagels 190, 283; Andrade). Children's contest powwows are one way in which Native Americans do this. One such powwow, in its third year in the Greater Houston area, provides a window into the continuity and change in the local Native American culture. This paper will examine how that powwow responded to an increasingly technologically connected world and the cultural blending between Native American and contemporary American culture that occurred as a result. Specifically, it will explore the role and impact of increased cultural fusion in not only this annual powwow but also in the lives of the participants. It is hoped that the paper will portray a representative image of the current balance between the preservation of tradition and cultural blending in the Native American Children's Contest Powwow scene.

The research for this paper was collected through an ethnographic account of the 3rd Annual Deer Park Children's Contest Powwow, a series of personal interviews of related individuals, and research into historical precedents. While the results of this comparison may not represent the experiences of all powwow participants, this paper serves as a particular

window into the world of Native American powwow. It begins with a look at powwows in Native American culture. It then presents a brief ethnography of the 3rd Annual Deer Park Children's Contest Powwow along with an explanation of the format of the event from its main organizer, Mr. Raul Andrade. After that, it presents interviews with an Alabama-Coushatta princess who performed at the event, a half-Native dancer at the event, and a non-Native photographer who was also present. The paper concludes by relating this research to cultural fusion in Native American communities at large.

A note on the terminology in this paper: the term non-native will describe individuals who are not of Native American descent because that is a common term used in publications on this topic (Axtmann 37; Berglund 14; Dueck 77; Hoefnagels 277); the term half-native will be used to refer to interviewee/dancer Alex Jensen, who has a Native American mother and a Danish father, as that is the term he preferred; when referring to the current overall culture in the U.S., the term contemporary American will be used to best cover the broad spectrum of different racial cultures that combine to build the identity of this nation.

1. Powwows

The word *powwow* is derived from the word *powwaw*, which means spiritual leader in Narragansett, an Algonquian American Indian tribal language (O'Brien). Historically, it refers to intimate tribal gatherings or memorials for the dead that have a spiritual purpose (Axtmann 1). Today, while powwows are still held for sacred purposes by many Native tribes, such as the Alabama-Coushatta tribe in the Greater Houston Area, they are held more popularly as intertribal contests for the socialization and culture preservation of Native Americans (Gardner). "Thousands of [these social] powwows occur every year" and they are open to the public, non-Natives included (Axtmann 1). While these intertribal contest powwows still center around the drumming, singing, and dancing of artists like the intimate tribal gatherings and memorials, they often include a cash prize for the best performers and the sale of food and artwork (Harvey). These more modern, social powwows serve as a "powerful way [for Native Americans] to assert [their] cultural identity and communicate with others" and a "unifying force" among Natives (Lehr 80; Axtmann 30).

2. Fieldwork

The majority of the fieldwork for this paper took place at the 3rd Annual Deer Park Children's Contest Powwow. This powwow, as the name suggests, is the third powwow to be held in Deer Park, Texas, specifically for Native Americans under the age of 18 from the surrounding region. Organized by a committee of elders from local tribes, led by Elder Raul Andrade from the Lipan Apache tribe, the event took place from 2:00 to 9:00 P.M. on June 15, 2019, inside an indoor gymnasium behind the Deer Park United Methodist Church. It involved children dancers from, but not limited to, the Alabama-Coushatta tribe, the Lipan Apache tribe, the Arapaho tribe, the Cheyenne tribes, the Caddo Nation, and the Navajo Nation.

Walking into the gym, one was hit with the aroma of Native American frybread and Indian tacos coming from the concession stand to the left of the entrance (see figure 1.). A row of stands with handmade Native American goods was positioned to the right, against the west wall. As one traveled further into the gymnasium, there were two narrow tables against the north wall hosting handmade crafts for a silent auction and a hallway leading to

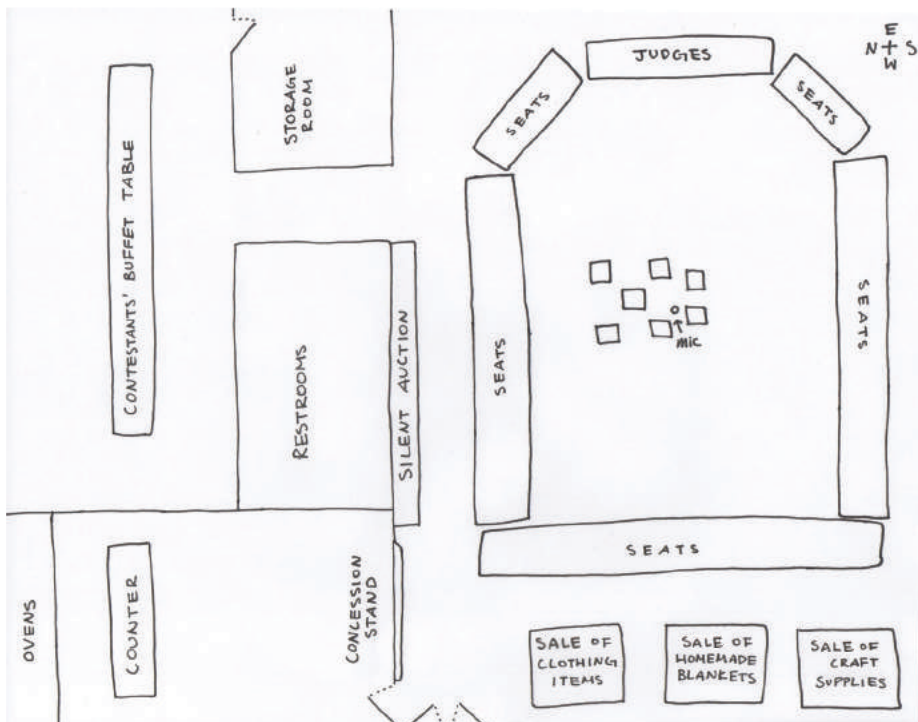


Figure 1.

The 3rd Annual Deer Park Children's Contest Powwow setup at 1331 E. 13th Street Deer Park, TX 77536. Jun 2019. Sketch by Author.

the restrooms, the lunch buffet area, and the storage area. Toward the center of the gym, there were 200 polypropylene plastic classroom chairs set up in a large U shape around the drum circle in the center of the room, and a 5–6 foot long judges' table at the room's eastern end. The drum circle was made up of seven plastic classroom chairs placed in an inner and outer circle. The five chairs in the inner circle centered around a southern drum with a mic, while the other two chairs in the outer circle were slightly further away. In this basketball-court-sized space, many things happened simultaneously.

From 2:00 to 6:00 P.M., storytellers, flute players, hoop dancers, and eagle dancers took turns entertaining audiences in the center stage, while parents of the contestants helped them get ready for the contest in the north-eastern and south-eastern corners. Vendors walked around the audience seats promoting their items, teenage girls and boys delivered concession stand orders across the gymnasium, and individuals crowded around the silent auction stands to place their bids. After 6:00 P.M., the performance segment ended and the competition began. Even though many more people settled down and became engrossed in what was happening around the drum circle, during this segment, the number of different things that took place outside of the drum circle continued to occur concurrently, which is typical of contest powwows.

Aside from the busyness, the event contained a number of other traditional features of Native American powwows. When interviewed, Mr. Andrade said that his powwow tries to follow the sacred aspects of a traditional powwow completely, including: making sure the entry during the Grand Entry faced west; dancers danced in a clockwise direction; they recognized the First Nations flag with the First Nations Eagle staff before all other flags; and that they did not step in the holy drum circle during the powwow. These all have sacred symbolic meanings (Axtmann 31). He also said that he sees getting those sacred aspects spot-on as being very important, because he wants the event to “teach honor and respect [for the Native customs] to [the] children.”

However, many aspects of this eventful powwow stood out as being unconventional. For one, this powwow was created specifically for the Native American children, while most powwows are mainly for adults with a children's subdivision. This powwow also allowed non-Natives to enter the arena to dance during the blanket dance segment, a recreational dance number held to gather money for the performers and organizer, typically reserved for only Natives. Furthermore, the silent auction at the event sold not only Native pieces of handicraft (such as a wooden flute and a beaded hummingbird keychain), but also non-Native items for kids (such as a toy RC car and a mini inflatable pool). Finally, the concession stand sold both Native

American snacks (such as Indian frybread and tacos) and popular American snacks (such as gummy bears and cola), which is not traditional.

When asked about why, given his mission to retain customs, he allowed these aspects of the event to modernize, Mr. Andrade replied that after he saw most powwows in the area “mainly focus on adult categories” with “the children contests [being] over rather quickly,” he decided to make the event all about the children because he wanted to give them a special channel “to shine and show what they have learned” about their heritage. Mr. Andrade also allowed all, Natives and non-Natives, to dance during the Blanket Dance segment because he and the other organizers wanted to make the non-Natives who took the time to learn about Native culture to feel welcomed and a part of the event. As far as permitting the sale of both non-Native items at the silent auction and at the concession stand, he said that it was because, while he wanted the youth to retain their Native culture, he also recognized that many of them have “assimilated to their [bigger non-Native] surroundings.” Mr. Andrade cites a large portion of them attending public schools and living outside the reservation as examples and said that these children are accustomed to consuming popular American goods. Because of that, he sees providing non-Native goods as a necessary accommodation to the needs of Native children growing up in contemporary America to ensure attendance, especially because this does not have to do with the spiritual aspect of powwows and is not part of a rigid tradition that cannot be broken. This reasoning shows that, whether Native Americans like it or not, the interactions between the mainstream American culture and Native culture is ever increasing and impacts the way Natives host their traditional events.

The unconventional practices described above are, in the end, all symptoms of the cultural integration of Native American culture with contemporary American culture. As for the future of the Annual Deer Park Children’s Contest Powwow, Mr. Andrade plans to continue putting them together for as long as he can and to expand them by involving more family members of the contestants and non-Natives in the area. He hopes to introduce a contest segment where the children and their parents dance side-by-side and compete together, to draw a bigger crowd and to give the event a greater “family atmosphere.” He also hopes for more non-Native media exposure, which is why he is very willing to talk about his powwow and allowed himself to be recorded and written about. All in all, Mr. Andrade’s powwow and children’s powwows in general are a part of a bigger movement across tribes to preserve Native culture for their youth. His firm stance on preserving the sacred aspects, along with looser regulations regarding non-Native representation in goods and those dancing, illustrates the balance he found in preserving

Native culture and adapting to the increased cultural blend in the Greater Houston Area.

While this section highlighted the major aspects of this powwow and some of the cultural fusions seen in it, the following sections will focus on exploring the cultural fusion that happens outside the event, in the daily lives of its participants.

3. Personal Interviews

This section presents interviews with a number of people who attended the 3rd Annual Deer Park Children's Contest Powwow, to get a better sense of how the growing interconnectedness of Native American culture with mainstream culture has impacted their lives. It also investigates the role each of the interviewees has played in fostering the harmonization of the cultures.

3.1 Reservation Life with Alabama-Coushatta Tribal Princess: Bianka Gardner

Bianka Gardner is a 16-year-old Alabama-Coushatta tribal princess who has lived on her tribe's reservation in Livingston, Texas all her life. She performed the Lord's Prayer in ASL Sign Language as an opening prayer for the Grand Entry at the Deer Park Children's Contest Powwow (see figure 2.). In this section, she discusses not only what her princess title means in terms of representing her Native culture to a greater audience, but more important, how cultural fusion plays into balancing life on the reservation with life in a public school where Native Americans are a minority.

When asked what the princess title means, she explained that she received her title by participating in the annual princess selection in the Alabama-Coushatta tribe. She elaborated by saying that the tribal princess committee in the Alabama-Coushatta tribe elects a princess each year, based on the participants' performance in four categories: frybread making, legend telling, native dancing, and an open talent category. According to the committee rules, each of the four categories is judged by three different judges who are not related to any competitors. Because the Alabama-Coushatta tribal reservation has a small population of fewer than 1200 people (Martin), Bianka said that her tribe actually prefers non-Natives as judges. Preference of non-Natives as judges is surprising, because it reveals that local Natives are willing to allow non-Natives to comment on the contestants' cultural identity. Even more surprising is the fact that if one chooses to do a dance for the open talent category, one is encouraged to do a contemporary American style of



Figure 2.

*Bianka Gardner on the occasion when she was crowned princess.
May 2019. Photograph courtesy of Bianka Gardner.*

dance such as Hip-Hop, ballet, or tap, instead of another Native dance. This kind of encouragement displays a high level of acceptance and integration of contemporary culture.

Speaking of the duties of a princess, Bianka summarized her main duties as to “represent [her tribe]”, “travel the different powwows”, and “make new friends” with people from all different backgrounds, Native and non-Native. She explained that although “it is a lot of work” and it is a heavy duty because “your tribe counts on you to represent them well”, being a princess is “an honor” and it allows her to “honor [her] family . . . honor [her] tribe . . . and honor everyone [she] knows”.

When asked about life on the reservation, Bianka started off by saying that she enjoys it because it is a really close-knit group and she is related to “almost everybody” there. She then revealed that she speaks both her Native language, Alabama, and English equally frequently at home, as do most people there. The younger Native generation speaking English as much as or more than their indigenous language seems to be a common situation across many tribes (Hoefnagels 158). Bianka’s thought that preserving her Native

language and culture is hard even on the reservation because they currently do not have any cultural programs seems to be echoed in different tribes as well (Hoefnagels 154). She did say, however, that their tribe is trying to push for Native American cultural classes at her high school, Big Sandy High School, and for greater Native American representation in the surrounding areas in general.

Big Sandy High School is located around 10 miles away from the Alabama-Coushatta tribe and has an enrollment of 225 students (National Center for Education Statistics). Bianka estimates that, currently, around 50 of those 225 students are at least part Native American. While a Native American concentration of around 22.2% (50/225) is dramatically higher than the 0.7% Texas average (2010 Census), Native Americans are still a minority in Bianka's Big Sandy High School. They have, however, found a way to incorporate their Native American culture into the mainstream culture at their school through the Native American Cultural Club they started. This club's 27 Native members produce a school-wide powwow show at the end of every school year to share Native American culture with everyone else. When asked about her friend group, Bianka said that while she is acquainted with every Native American at her school, a lot of her close friends are also non-Native, and she doesn't feel that anyone at school "looks at [her] differently" because she is Native. From the way she has described herself, Bianka and many other Natives seem to have acclimated to a primarily non-Native culture successfully while retaining aspects of their own Native culture. In addition, they are serving as the next generation of communication between the contemporary American culture and their Native culture.

3.2 Familial Cultural Blend with Half-Native Dancer: Alex Jensen

Alex Jensen is an 18-year-old half-Native dancer who attended the 3rd Annual Deer Park Children's Contest Powwow (see figure 3.). In this section, he discusses the cultural blending that has taken place in his half-Native life. Alex's mom is of Choctaw, Cherokee, and Chippewa heritage and sits on the local Annual Deer Park Children's Contest Powwow Committee of Organizers. His dad is of fully Danish descent and engages more with the Danish community. Alex, because of his unique background, does not live on a Native American reservation like many of the other dancers from the contest powwow. Instead, he lives in a typical suburban neighborhood filled with mostly non-Natives. His living location, coupled with his cultural heritage, has made keeping in touch with the Native community more difficult for him than for most other Native Americans who are connected to the community simply by the location of their home. When asked about



Figure 3.

*Alex Jensen at the United San Antonio Powwow.
Feb 2018. Photograph courtesy of Alex Jensen.*

how he builds/ maintains connections to the Native community, he said that “outside of [attending] powwows, it’s mostly through social media and get-togethers for crafts.” He elaborated by saying that there are “different Facebook pages that both [his] mom and [himself] are a part of” that keep them updated on community news and events.

When asked about how his social group relates to his distinctive background, he said that, similar to Princess Bianka Gardner, “a lot of [his] friends are part or full-blood Native American,” but he also has friends from “all different backgrounds, like Ireland, Africa, or other European countries.” He added that although around half of his close friends are Native, he does not think about whether someone is Native when he makes friends with them. Furthermore, he often does not see a distinct difference between the way his Native friends and his Non-Native friends live. That fact was surprising because it reveals that, with the increasing connectivity of the world, the customs of some Native Americans and some mainstream Americans have merged to the extent of being indistinguishable.

Later, when discussing the cultural clashes that occur in his family, he said that, to him, his mother and father’s cultures “are not really that different” because “both are known as very happy and moral cultures in that they promote good morals.” He sees more similarities than differences between the two cultures, which made it easy for him to feel a part of both cultures at the same time. He did note, however, that there were instances when he was “faced with the opportunity to learn more about both cultures but [he had] to choose one because [he] can’t do both at the same time.” An example included deciding between going to a powwow and a Danish festival that took place on the same weekend. To this end, Alex stressed again that even though Danish and Native American “are two entirely different cultures, . . . they are kinda similar” at the same time. For him, being able to draw on both of those backgrounds has enhanced his understanding of life in that it has allowed him to focus on commonalities that unite people instead of differences that tear people apart.

Alex is also very optimistic about the future of powwows and Native American culture. He said that he “[doesn’t] think it’s going away by any means” because events such as the annual Gathering of Nations Contest Powwow in New Mexico is so huge and so full of life. He does hope, however, that outside forces such as the Boy Scouts of America, which he is a part of, can provide “a channel” for more people to be exposed to powwows. All in all, Alex’s half-Native background has only created more interest within him to learn about Native American culture, Danish culture, and other cultures. He wishes that everyone could come together to create more understanding between people.

3.3 Spreading of Native American Culture with a Non-Native Powwow Enthusiast: Richard Houghton

Mr. Richard Houghton is a non-Native U.S. Navy veteran and a photographer who was taking photos at the 3rd Annual Deer Park Children's Contest Powwow (see figure 4.). In conversations, he shared how and why, as a photographer, he chooses to act as a vehicle for cultural fusion between the mainstream culture he was born into, and the Native culture he has grown to love.

Mr. Houghton grew up in Texas with fully Caucasian roots and came into the Native American cultural scene more than a decade ago, when he became fascinated with Tlingit totem poles while living on the Northwest Coast. His fascination with totem poles soon led him to “[seek] out different shows and fairs” put on by various Native American tribes. Participating in these has led him to have profound respect for Native Americans and their culture. He stressed that “the backbone of [their history] is amazing” and their “urge to continually fight back against oppression, against racism, against the things that even go on now” is even more touching. When asked how photography and capturing Native artistic expressions factored into all of this, he said that while he wasn't able to afford to pursue photography in his earlier years of participating in the Native American cultural scene, their art (such as the totem poles) is definitely what drew him in the most.



Figure 4.

*Richard Houghton on the occasion of an at-home photo shoot.
Jul 2019. Photograph courtesy of Richard Houghton.*

When asked about his experience with the 3rd Annual Deer Park Children's Contest Powwow more specifically, Mr. Houghton said that his purpose in attending this powwow has shifted from just "to look at art". Now he is aware of "a deeper meaning of why the nations get together" to host powwows in the first place: to "ensure [the survival of] their culture". To this end, powwows now carry a greater significance to Mr. Houghton, and this event with its specific focus on passing Native American culture down to the children became especially meaningful to Mr. Houghton. Not surprisingly, when asked what he liked most about this specific event, he said it was "the children" and "the freedom" the children had to explore and express their cultural background. He also noted that, at least in his experience, this is the first powwow specifically for children that he has ever heard of or attended, which makes the event a unique experience.

With the photographs he has taken of the 3rd Annual Deer Park Children's Contest Powwow, and helped by a friend, Mr. Houghton has created a slideshow about the event and the Native community in the Greater Houston Area. He will be giving the product back to the organizers of this powwow to use for free as a promotion for the annual powwow in the future, and will also share it with the local photography club, which he is a part of, to introduce Native American culture to a greater audience. Mr. Houghton said that the reason he is willing to devote so much time to being a part of the local powwow scene and spreading Native American culture is that Native American culture has also taught him a lot about life. He said that being a part of the Native American community has shown him that "we are all different and we have to understand and appreciate different cultures, different music, and different approaches, especially [the fact] that they're still here and still preserving their culture." The above lesson is why he believes that it is "absolutely important" to expose non-Natives to Native culture and why he is a part of the local powwow scene.

4. Conclusions

Through an observation of the 3rd Annual Deer Park Children's Contest Powwow, personal accounts from attendees, and writings on historical precedents, it becomes evident that great amounts of contemporary American culture have "made inroads" into traditional Native American culture, as Browner has noted in her broad-based study of powwows in the U.S. (Browner 18). The allowance of non-Natives to participate in the blanket dance, the existence of non-Native foods at the concession stand, and the sale of non-Native items at the silent auction are just a few examples. In the larger powwow scene, the diverse friend group of Princess Bianka,

the family background of dancer Alex (Native American mother, Danish father), and the involvement of non-Native photographer Mr. Houghton provides a look at the greater impact of such cultural blending. This cultural fusion in the personal lives of all the interviewees also empowers them to be a vehicle of further cultural understanding in their individual ways.

With the increasing global connectivity through advancements in technology, the trend of cultural fusion in Native communities is only going to continue to increase. Therefore, to ensure that the rich Native American heritage survives and is passed on, we must look at how we can present such a culture in a modern setting to today's youth while preserving the core aspects that made it worth preserving. While different people have different views on what the ideal balance between the preservation of traditions and modernization looks like, the 3rd Annual Deer Park Children's Contest Powwow showcases one possibility. By taking a firm stance on preserving the sacred aspects, and being open to negotiating on all other aspects, this powwow not only drew over 100 Natives, but also offered a look at their culture to a handful of non-Natives. Ann Axtmann claimed in 2015 that with close observation, one can see that powwows are already "everywhere" in our contemporary American society (Axtmann 3). Even so, events such as this children's powwow can help powwows gain an even broader audience and play an even larger role in the fabric of the Greater Houston Area's culture specifically, and in American culture as a whole.

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Human Intuition, Perception, and Execution of a Five-Beat Versus a Seven-Beat Rhythmic Cycle

Sahana Prasanna

Author Background: Sahana Prasanna grew up in the United States and attended Monta Vista High School in Cupertino, California. Her Pioneer research concentration was in the field of Music/Music Theory and titled “Analysis of Musical Rhythm.”

Abstract

Humans have been exposed to meters and rhythms for most of their lives, most commonly binary meters. However, the focus of this study is on the most uncommon, irregular metrical structures: the five-beat and seven-beat rhythmic cycles. Experiments were conducted to measure participants’ ability to entrain to music in these cycles based on their timing, number of attempts, and previous musical experience. Extensive analysis of the music chosen and external factors have been taken into account and it can be concluded that when comparing human perception and execution of a five- and seven-beat rhythmic cycle, people are likely more able to entrain to and perceive all aspects of the seven-beat cycle better than the five-beat cycle.

1.0 Introduction

Meter is essentially a compilation of sounds that are heard in regular time intervals. It allows us to, in a way, predict the future; we are able to estimate the next time an invariant sound will take place, and by doing so, foresee the time ahead. Aligning one’s attention and expectations to an invariant sound is called entrainment. Musical rhythm and meter have developed as a result of this innate human capability. Many studies on meter and humans have shown

that we are able to consistently repeat and replicate regular intervals of temporal sounds, which is essentially the foundation of meter.¹

Meter is fundamentally made up of many different metrical layers that produce musical motion and continuity. The tactus is considered to be an interpretive layer and the most intuitive metrical layer in music, the one that is perceived the most naturally. Although the tactus is completely periodical with no variation, without it in the roots of music, rhythm and meter would not be able to exist.² There are several metrical structures that occur in many genres of music, all based on the foundational tactus.

Metric Classification	Sample Meters	Percent Occurrence
simple duple	2/2, 2/4, 2/8, 2/16	27.4%
simple triple	3/2, 3/4, 3/8, 3/16	32.0%
simple quadruple	4/2, 4/4, 4/8, 4/16	27.2%
compound duple	6/2, 6/4, 6/8, 6/16	9.4%
compound triple	9/2, 9/4, 9/8, 9/16	1.3%
compound quadruple	12/4, 12/8, 12/16, 12/32	1.9%
irregular	5/4, 7/8, etc.	0.8%

Figure 1.

Metric structures and their occurrences based on surveys from thousands of Western Classical compositions.³

Based on Figure 1, the most common meters are duple and quadruple meters, otherwise known as binary meters. However, the focus of my study is precisely on the most uncommon, irregular metrical structures: the five-beat and seven-beat rhythmic cycles. Though these cycles may be rare in Western Classical music and most other genres, they are actually key rhythmic cycles in *Carnatic*, or South Indian Classical music. Carnatic music, a prominent art form in South India, traces its roots back to the 12th and 13th centuries. Its grandeur was brought into light at the beginning of the 19th century, due to the works of the three great composers: Thyagaraja, Muthuswami Dikshitar, and Shyama Shastri.⁴ Various structures in the music further developed,

1 London, Justin. *Hearing in Time: Psychological Aspects of Musical Meter*. Oxford: Oxford University Press, 2012, 1.

2 Ibid.

3 Huron, David. *Sweet Anticipation: Music and the Psychology of Expectation*. MIT Press, 2008, 195.

4 Kuckertz, Josef. 2019. "Die Kunstmusik Südindiens Im 19. Jahrhundert." In *Collected Work: Musikkulturen Asiens, Afrikas Und Ozeaniens Im 19. Jahrhundert. Series: Studien Zu Musikgeschichte Des 19. Jahrhunderts, No. 31* Published by: Regensburg,

such as musical scales called *ragas*, and rhythmic beat cycles called *talas*, the latter of which are studied in this paper.

Within all the *talas*, the basic ones consist of 3, 4, or 8 beats in a cycle. Additionally, there are also thousands of compositions set to *tala* cycles of 5 and 7 beats, known as *chapus*. Unlike all the other *talas*, these ones are of an unknown origin, with no particular person coming up with a system.⁵ They were discovered due to the many compositions already created, using the feel and movement of a five- or seven-beat cycle. In Carnatic music today, the five-beat cycle is executed by tapping one's hand to the first, third, and fourth beat, and the seven-beat cycle is done by tapping the hand to first, second, fourth, and sixth beats.

Because the origins of these *chapu talas* are unknown, I hypothesize that they have an aspect of human intuition to them. After all, they are very loosely structured and only follow the rhythm of the song already composed. For these songs to be originally composed, the five or seven beat cycles must have already been ingrained in the musician and composer in order to implement them in their music. My overall goal for this research was to not only discover if humans have an innate capability for these cycles, but to also find out how their execution and perception differs between the five- and seven-beat cycles.

The term intuition is widely defined as exercising one's imagining based on previous sensory experiences.⁶ However, enculturation and sociopolitical context to intuition plays a key role in aligning one's expectations and "intuition" to a specific musical style, or really anything else that requires a level of intuition. For example, John Dewey and Leonard Meyer, American Musicologists and writers, elaborated on expectations in music as both a natural and learned phenomenon. The response or anticipation of music is due to the habits of an established pattern, and when this pattern is interrupted, that is when the listener responds emotionally or changes their habits.⁷ Going back to the five-beat and seven-beat cycle, the intuition of the listener to these

Germany: Gustav Bosse, 1973. Pages: 97–130. (AN: 1976–06498). Regensburg: Gustav Bosse. Accessed August 22. <http://search.ebscohost.com/login.aspx?direct=true&db=rft&AN=A390890&site=ehost-live&scope=site>.

5 Vedavalli, R. 2014. "Talas in Carnatic Music." *Sruti*, no. 355 (April): 36–37. <http://search.ebscohost.com/login.aspx?direct=true&db=rft&AN=A863156&site=ehost-live&scope=site>.

6 Swanwick, Keith. *Musical Knowledge: Intuition, Analysis and Music Education*. Routledge, Taylor & Francis Group, 2016.

7 Sparshott, F.E. "Meyer, Leonard B." *Grove Music Online*, 20 Jan. 2001, www.oxfordmusiconline.com/grovemusic/view/10.1093/gmo/9781561592630.001.0001/omo-9781561592630-e-0000018551.

cycles would depend on their habits and their previous musical experience, but the way they respond to them could be interpreted as an outburst of their natural or emotional states.

Even though there are many more compositions in Carnatic music set to the seven-beat cycle than the five-beat cycle, I initially hypothesized that the five-beat cycle would be easier to entrain to due to its relative simplicity. This assumption stemmed mostly from the fact that the five-beat cycle is shorter than the seven-beat cycle, and therefore, supposedly requires less of an effort to entrain to. However, as the experiments progressed, I determined that remarkably, most subjects found all elements of the seven-beat cycle easier to entrain to.

2.0 Background

I chose this research topic as I have been learning and performing Carnatic vocal music for the past thirteen years and it is now an integral part of my life. I wanted to combine Carnatic music with another one of my passions, the biological sciences, so I decided to integrate musical rhythm with cognition and research human intuition, execution, and perception.

The basics of talas in Carnatic music begins with the Suladi Sapta Talas, the seven basic cycles. Any tala is done usually using the right hand, while singing simultaneously. In each cycle, there are two parts: the laghu, which is done by tapping individual fingers, and the dhrutam, which is a tap and then a flip of the hand.



Figure 2.

A depiction of how to execute the dhrutam, a part of some tala cycles.

Each of the seven talas can have 3, 4, 5, 7, or 9 laghus and up to 2 dhrutams. The simplest of these is known as Adi talam, which has 8 beats in its cycle. The three composers, along with many others, have composed thousands of songs, or krithis, in these talas and more. The chapus, the five- and seven-beat cycles I conducted my study around, are another category of talas.

3.0 Materials and Methods

To answer my question regarding the intuition, differences in perception and execution of the five-and seven-beat cycle, I obtained data from 29 participants who had little to no experience with Carnatic music. My procedure started with a survey about the extent of their musical training and background in Carnatic music, in which I aurally asked them about their musical experience; I made sure that the participants' exposure to Carnatic music was minimal or nonexistent. This was to ensure that the factor of statistical learning and exposure did not influence the outcomes of entraining to the metrical patterns based on pure intuition and pattern detection. All of the data was collected aurally, with myself only playing recordings and refraining from showing the participants any sort of notation. As I was asking the participants to perform the tasks detailed below, I videotaped them and used the video recordings to gather the necessary data.

3.1 Part One of the Experiment

The experiment had three parts in total, and each part contained three sections. The first part of the procedure was a control task, where I asked all participants to tap, with their hand or finger, to various beats in a simple duple meter march.⁹ I chose this march due to its simple, easily noticeable rhythm, in order to extrapolate the participants' musical experience and comfortability from it. I did not want this training section to parallel the experiment section in any way because I wanted to test their intuition of the five and seven beat cycles, which would be most accurate if they did not hear it beforehand. I first asked them to tap to the fastest, constant beat of the piece, and dubbed it "tapping to the beat." Second, I asked them to tap once every 2 beats, which I taught as "tapping to the slice," which I will refer to as the sub-cycle. Third, I asked them to tap once every 4 beats, and designated that process as "tapping to the beat cycle." I timed how long it took for each of the participants to perform these steps as a test for their proficiency and a comparison time for the next part of the procedure. Timing was involved because I assumed that the shorter the participant took to perform the task successfully, the more experienced they were with musical rhythms.

⁹ <https://www.youtube.com/watch?v=PJI1AbsDOPQ> starting at 7:48 at 1.5x speed, to closer match the speed of the periodic intervals of the subsequent songs.



Figure 3.

Three measures that show tapping to the beat, tapping to the sub-cycle, and tapping to the beat cycle respectively in a 4/4 time signature.

These three distinct sections (tapping to the beat, tapping to the sub-cycle, and tapping to the beat cycle) were performed in order to teach the participants the required steps for the following part of the experiment. To further instruct them, I gave them an example of the beats, sub-cycles and beat cycles again, without a song, now with a six-beat cycle instead of the four-beat cycle of the march.



Figure 4.

These two measures show tapping to the beat and tapping to the beat cycle, respectively.

However, I wanted to make it clear that tapping to the sub-cycles does not have to be an equal division of the measure, so I demonstrated this section in three ways.



Figure 5.

The three measures are different ways to execute the sub-cycles of a 6/4 time signature, showing that the taps do not need to be evenly spaced, but rather tapped to the rhythm of a song. It can be tapped any way as long as it fits in the full cycle, which is 6 beats in this example.

3.2 Part Two of the Experiment

After the control tasks and instructing the participants about the three types of beats, I tested their entrainment to the five-beat cycle. I played a Carnatic *krithi*, or song, named “Paridaana Michite,” composed by Thyagaraja, and played by violinist MS Gopalakrishnan.¹⁰ I chose an instrument instead of a vocalist, because vocalists tap the tala themselves and it may be audible for the participants. This specific song was chosen because it starts

¹⁰ <https://www.youtube.com/watch?v=L-d7wJo0Kps> starting at 3:36.

on the downbeat of the cycle, making it relatively easier to figure out the rhythm, and because it is a common Carnatic song and a staple of the five-beat rhythmic cycle.

Similar to the previous step, I asked them to tap to the beat, sub-cycle, and beat cycle without telling them that it was a five-beat cycle. For both the five- and seven-beat cycles, the sub-cycles are the same as how the talas are put in Carnatic music. As the participants were tapping to the various steps, I timed how long it took for them to successfully entrain to the beat. Most were not able to successfully tap the sub-cycles and beat cycle before one minute of the recording, so I had to provide a demonstration, asking them to mirror me. In that case, I noted how many cycles of help they needed, and whether they were able to continue tapping accurately after that help. Overall, all participants fit into one of three categories: fully successful, successful with help, and unsuccessful even with help.



Figure 6.

The three measures are tapping to the beat, the sub-cycle, and the beat cycle for the five-beat song, Paridaana Michite. The sub-cycle could be tapped in another similar way; for example, the fourth beat in the measure could be just a rest, and I accepted those as successes if the participant did it themselves. The sub-cycle structure above is in alignment with the song and is also the tala, so I decided to demonstrate it this way.

3.3 Part Three of the Experiment

The final part of the procedure was to test the participants' ability to entrain to a seven-beat cycle. I played a different krithi, called "Ninnu Vinaga," composed by Shyama Shastri, and also played on the violin by MS Gopalakrishnan.¹¹ This song was chosen because the structure of the song corresponded heavily to the beat cycle and would make it relatively easier for the participants to find the rhythm compared to other Carnatic songs. In both the five- and seven-beat songs, I played the beginning section of the krithi, called the *pallavi*, which is essentially the chorus of the song. The *pallavi* is comprised of one line of four beat cycles that repeats itself many times, with different variations on the line each time. This makes it easier for listeners to identify patterns and try to find recurring notes or rhythms that help with entrainment to the beats.

¹¹ https://www.youtube.com/watch?v=vg6XY_HQcdE starting at 5:33.

Again, I asked them to tap to the beat, sub-cycle, and the beat cycle. I timed how long they took to successfully tap and demonstrated it if they were not able to. The sub-cycles, seemingly harder to figure out than the five-beat cycle, were made discernible by the emphasis of parts of the song.



Figure 7.

The beat, sub-cycle, and beat cycle for the seven-beat song, Ninnu Vinaga.

Some participants did not perform the sub-cycles the exact same way as the tala, and some did not tap to the beat cycle on the first beat, rather the third, and continued every seven. Since those were technically correct and, were a way of entraining to the beats, I still marked them as successful.

4.0 Results

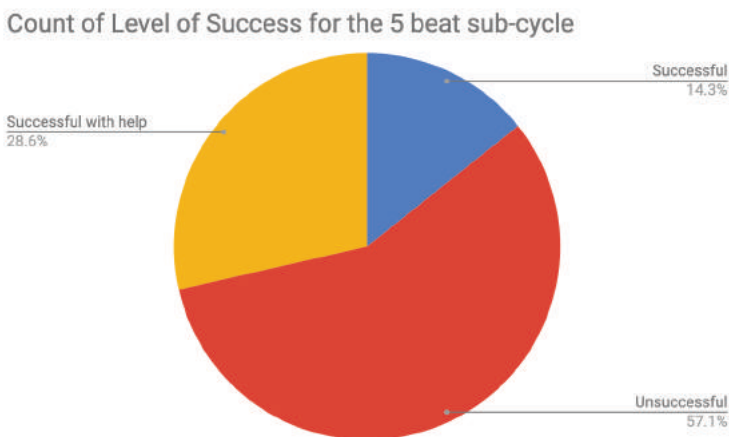
Based on the data gathered from the 29 participants, it appears easier for humans to entrain and execute all aspects of a seven-beat rhythmic cycle than a five-beat one. The participants who were able to tap without any demonstrations from me were considered successful, the ones who needed my help but were able to tap accurately afterwards were considered successful with help, and those who were not able to, even with my help, were labelled as unsuccessful. 57.1% were unsuccessful in tapping to the five-beat tala, or sub-cycle, and 39.3% were unsuccessful in tapping to the five-beat cycle. However, only 28.6% and 21.4% were unsuccessful in tapping to the seven-beat tala, or sub-cycle, and the beat cycle, respectively. The category with the greatest number of successes was the seven-beat cycle, with the number of successes without help even greater than successes with help. The smallest number of successes was found in the five-beat sub-cycle, where more than half of the participants were unable to entrain to it even with help (Fig. 7).

Additionally, there is not a clear correlation between the amount of time participants took to tap to the beats of the control task and the level of success they achieved for the five- and seven-beat cycles. For the five-beat sub-cycle, the participants who took less time for the control task actually had a lower level of success than the participants who took more time. However, for all the five-beat cycles, seven-beat sub-cycles, and seven-beat cycles, the people with the highest level of success, on average, took the least amount of time for the control task. The five-beat sub-cycles may be an outlier, and in that

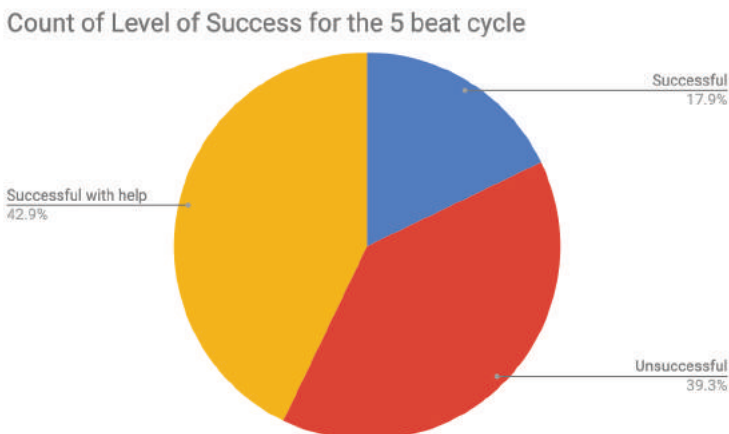
case, there is a very slight negative correlation between the level of success and the amount of time taken for the control task (Fig. 8).

A few more observations that were not related to the initial intent of the study were made. An average of 36% of participants assumed that the sub-cycle for both five- and seven-beat cycles were every 2 or every 4 beats, even after knowing that it was uneven. Only after I demonstrated the cycle for them multiple times did they stop tapping to these binary rhythms and start following the actual sub-cycle. Furthermore, even tapping to the beat (the first step of each part of the procedure) for the seven-beat cycle was easier to entrain to than the five-beat cycle (Fig. 9). On average, participants were able to entrain to the seven-beat song in a shorter amount of time.

(a) Count of level of success for the five-beat sub-cycle

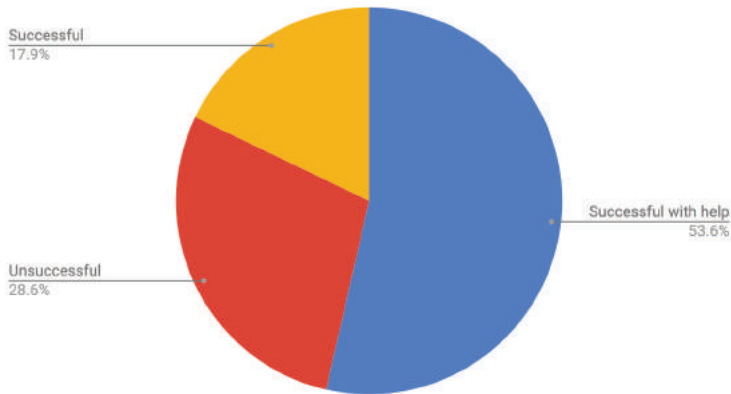


(b) Count of level of success for the five-beat cycle



(c) Count of level of success for the seven-beat sub-cycle

Count of Level of Success for the 7 beat sub-cycle



(d) Count of level of success for the seven-beat cycle

Count of Level of Success for the 7 beat cycle

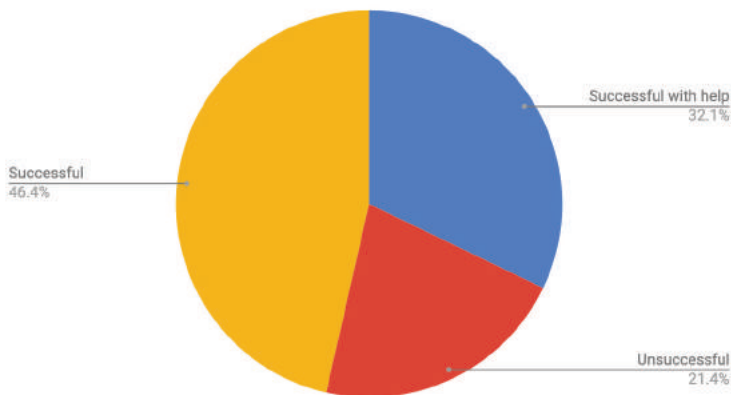
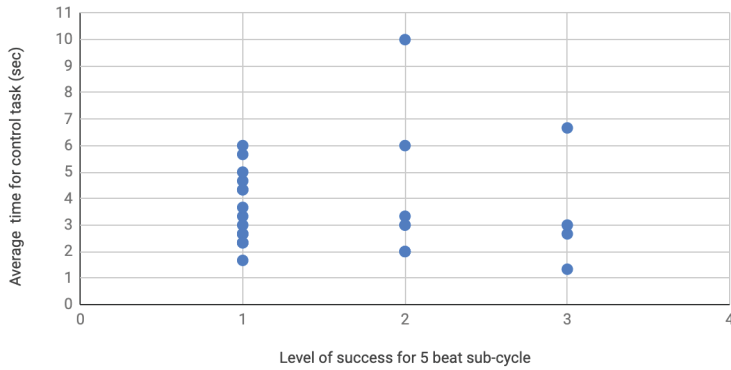


Figure 8.

Pie charts showing the percentage of participants that were successful, successful with help, and unsuccessful for tapping to the sub-cycle and cycle for the five and seven-beat cycles. In (a), the sub-cycles for the five-beat cycle are shown. In (b), the beat cycle for the five-beat cycle is shown. In (c) the sub-cycles for the seven-beat cycle are shown. In (d) the beat cycle for the seven-beat cycle is shown. Since every participant required different levels of demonstration, it was not possible to assign a numerical value, such as the time taken to entrain to the tapping, to anyone other than participants who achieved success without help. Hence, the three levels of success are used to show ability to entrain.

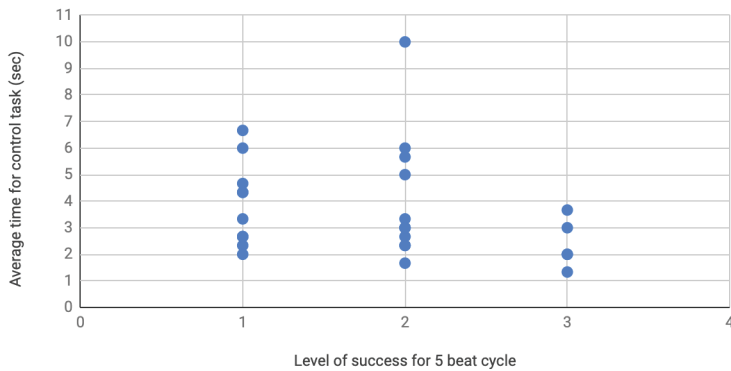
(a) Level of Success for five-beat sub-cycle vs. average time for control task

Level of success for 5 beat sub-cycle vs average time for control task



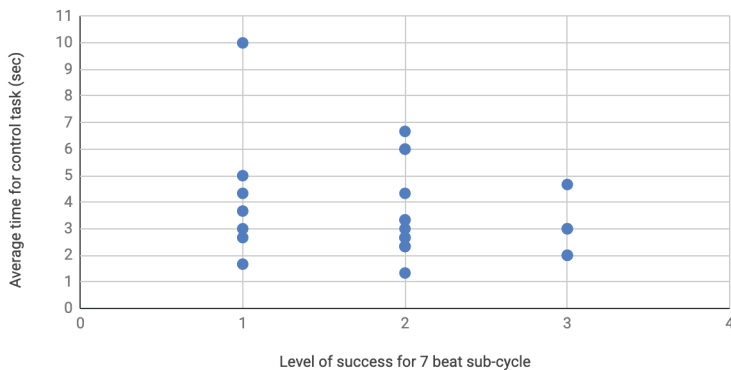
(b) Level of Success for five-beat sub-cycle vs. average time for control task

Level of success for 5 beat cycle vs average time for control task



(c) Level of Success for seven-beat sub-cycle vs. average time for control task

Level of success for 7 beat sub-cycle vs average time for control task



(d) Level of Success for seven-beat cycle vs. average time for control task

Level of success for 7 beat cycle vs average time for control task

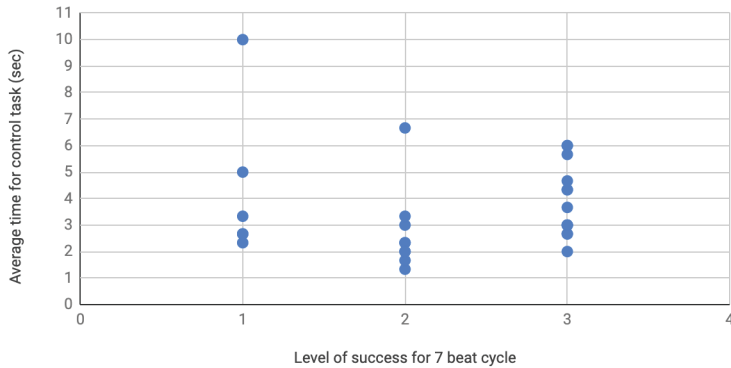


Figure 9.

Scatterplots showing the level of successes for (a) five-beat sub-cycle, (b) five-beat cycle, (c) seven-beat sub-cycle, and (d) seven-beat cycle versus the average amount of time taken for the control task. In the x-axis, the whole numbers 1, 2, and 3 correspond to unsuccessful, successful with help, and successful respectively. The average time for control task is the average of all the times taken for participants to tap to the march's beat, sub-cycle, and beat cycle.

Time taken to tap to the beats of the 5 beat and 7 beat cycle

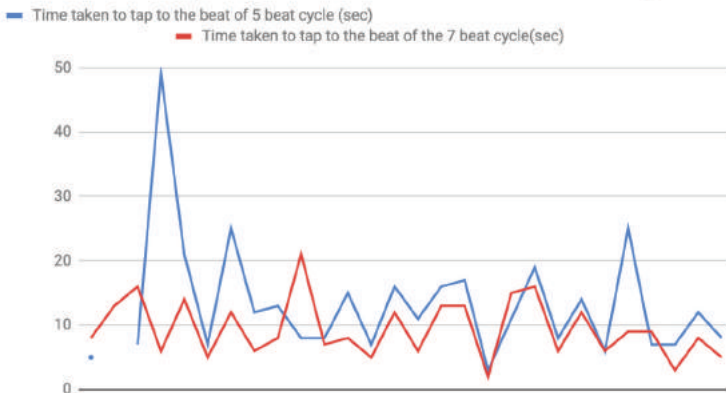


Figure 10.

The time taken in seconds to tap to the beat of the five-beat and seven-beat cycle. Each participant's time is shown on the intersection of two lines, or the peaks. The area of the five-beat is significantly larger than the seven-beat, showing that participants entrained faster while tapping to the seven-beat.

5.0 Discussion

My findings about the perception and execution of a five-beat versus a seven-beat cycle differed from my initial hypothesis of the five-beat cycle being easier to entrain to; in general, participants found it easier to entrain to the seven-beat cycle. To investigate the possible reasons why, I analyzed both the songs I played, and their cues and hindrances for entrainment throughout each of the five-beat and seven-beat sub-cycles and cycles.

5.1 Song Analysis

Five-beat cycle:

To find the continuous, periodic beat for the five-beat cycle *krithi*, *Paridaana Michite*, the main cue is the *mrudangam*, or South Indian drums that accompany the entire song. A few seconds into the first line, the *mrudangam* comes in with a steady beat. Although there are many variations and changes in the *mrudangam*'s length of notes and styles, it is always tied to this beat; therefore, it is possible for unfamiliar listeners to quickly identify and tap to it. The song itself, as well as the *mrudangam*, is rhythmically precise, and does not diverge from the set tempo. Because of the clear-cut alignment to the tempo, most participants were able to entrain to this beat without any assistance.

In a five-beat cycle in Carnatic music, the sub-cycles are tapping one's hand on the first, third, and fourth beats of the cycle (Fig. 5). While this is common knowledge to those who have studied Carnatic music for years, it may be a little harder for uninitiated listeners to figure this out. However, it is feasible using signals from the song. The first few times the line is repeated, the song has one sustained note for the first two beats in the five-beat cycle, and oscillations and variations on the third to fifth beats. Using this as a clue, one can separate the cycle into 2 + 3, achieving success on the sub-cycle part of the experiment. The division of the last 3 beats into 1 and 2 was up to the participant. Since it makes it easier to keep a steady cycle, my demonstration included it.

The last step of the procedure was to tap once in the entire cycle, preferably on the downbeat (Fig. 5). The song again provides clues. On the first beat of the cycle, there is always the start of a new phrase in the song, which can be heard by the difference of the scale degree of notes compared to the other notes around it. The violinist's bow stroke is a little more emphasized as well. At the beginning, there is a single sustained note every time a new cycle starts, which could help entrainment. This is taken away as the song

progresses, which might have held back listeners from fully entraining to the beat cycle.

Seven-beat cycle:

The beat of the seven-beat cycle, like the beat of the five-beat cycle, is most highlighted by the constant tapping of the mrudangam. A few phrases into the song, it is played with syncopation, which may be a cause of hindrance, but by then, most participants were already entrained to the constant beat and were able to continue performing it accurately.

The sub-cycles, or the actual tala of the seven-beat cycle, are the most prominent out of the three procedures for the krithi. It is customary to tap the beats as 1 2 3 4 5 6 7 for this song, the places to tap being bolded (Figure 6). The song starts with a single note for the first 2 beats, another note for the next 2, and 2 different notes on the 5th and 6th beats of the cycle. This clear variance in notes and emphasis makes the sub-cycle very noticeable. However, the line in the pallavi is 4 full cycles, and the clear subdivisions are only present in the first 2 cycles, which may make it confusing as the pallavi progresses and variations in the line increase. Despite this, many more subjects were successful in entraining to this compared to the five-beat cycle, which could be a result of the obvious divisions of the cycle.

The only obvious cue for the full cycle is the repetition of the melodic and rhythmic pattern of 4 cycles in the pallavi. The downbeat on 1 in every seven-beat cycle is significant only in the first note of a line, and as the line repeats, the first note of every 4 tala cycles. The other downbeats are not particularly emphasized; some are drowned out as the phrase continues from the previous cycle. However, many more subjects were able to entrain once every cycle for the seven-beat cycle than for the five-beat cycle, which is unexpected as the phrasing of the five-beat krithi actually makes it easier to entrain to. Furthermore, around 10% of the subjects thought the downbeat was the third beat in the seven-beat cycle (Fig. 9). This is possibly due to a drastic note difference on the 3rd beat of the 2nd cycle in the line. As this repeats itself, subjects may have processed that note as the downbeat, and continued every 7.



Figure 11.

Around 10% of participants tapped to the seven-beat cycle with the downbeat of the third beat of the cycle. Yet, they were still able to entrain as they tapped once every seven-beats. This placement does not give clear indications of any emphasis, but those who tapped here managed to still entrain to the seven-beat cycle.

In analyzing these cues, it is not evident that the songs themselves may have contributed to the greater entrainment success of the seven-beat cycle. Both Paridaana Michite and Ninnu Vinaga have similar indications of the beat. The only exceptions may be the more explicit indication for the seven-beat sub-cycle in Ninnu Vinaga than the five-beat sub-cycle. In the five-beat cycle, the phrasing of the music in Paridaana Michite clearly establishes the beat cycle more than the seven-beat cycle, although participants performed better in the seven-beat cycle.

5.2 IOI and BPM Analysis

For another possible explanation, the inter-onset interval (IOI), which is the time span between two articulations, and beats per minute (BPM) can be examined. Many studies have led researchers to believe that the ideal tactus, or the duration of a pulse that is neither too long nor too fast, is around 100 bpm (beats per minute). They also determined that not all periodic stimuli can be entrained to, as some are too long or too short. The shortest interval we can hear has an IOI of around 100 milliseconds (ms), and the longest has an IOI of around 5 or 6 seconds. These boundaries make up a “temporal envelope” of rhythm.¹² Music theorist Peter Westgaard created the following table based on that knowledge and other research.

Figure 12.
*The generally ideal tactus shown in IOI and BPM format,
with commentary on its ability to be entrained*

BPM	IOI (ms)	Tempo comment
30	2000	too slow to be useful
42	1414	very slow
60	1000	moderately slow
80	700	moderate
120	500	moderately fast
168	350	very fast
240	250	too fast to be useful

Similarly, I created a table of the IOI and BPM for the five-beat and seven-beat cycle songs.

¹² London, Justin. *Hearing in Time: Psychological Aspects of Musical Meter*. Oxford: Oxford University Press, 2012.

Figure 13.

The metrical envelope, in BPM and IOI (ms), of Paridaana Michite, the five-beat cycle song, and Ninnu Vinaga, the seven-beat cycle song. The BPM and IOI are shown for every beat, every 2 beats, and every cycle (which is either 5 or 7 beats depending on the song). The sub-cycle cannot have its own IOI or BPM because it contains irregular intervals, so every 2 beats is displayed instead.

	Paridaana Michite— five-beat cycle		Ninnu Vinaga— seven-beat cycle	
	BPM	IOI (ms)	BPM	IOI (ms)
Every beat	160	375	180	333.3
Every 2 beats	80	780	90	666.7
Every cycle	32	1875	25.7	2333.1

It is noticeable that the IOIs of every beat and every cycle are not “useful,” or very hard for humans to be able to perceive and execute. However, Westgaard’s table is based on isochronous stimuli without any background music, so when also given the music, most of these tempos remained useful and were able to be entrained to. The reason as to why more people were able to entrain to the seven-beat cycle than the five-beat cycle could be because its BPM and IOI are 25.7 and 2333.1, respectively, which have a tempo comment of “too slow to be useful.” Since this is not able to be entrained to anymore, participants would have needed to access other types of cognition, not just entrainment, to be able to follow that beat. For the five-beat cycle, on the other hand, the BPM and IOI are 32 and 1875 and not above the 2000 IOI limit, so participants could still entrain to it. The various kinds of cognition that would have been required are legitimate questions for further study.

5.3 Binary Default

Participants were also fixated on tapping every 2 or 4 beats during the sub-cycles, even after I mentioned that the sub-cycles were uneven. An average of 36% of participants thought that the sub-cycles for both five- and seven-beat cycles were every 2 or every 4 beats. Many other genres of music that the participants have been exposed to contain these binary beat cycles, which is why a lot of people were centered around it. Another reason is that the BPM for every two beats for the songs is very close to 100. The fact that 100 BPM is the ideal tactus for most people makes them more inclined to entrain to a beat that is close to that number.

Additionally, based on David Huron’s book, *Sweet Anticipation*, there is an expectation of a binary default in western musicians and listeners. According to researchers’ neuropsychological data at the University of Bourgogne in

France, subjects were “accenting the odd-numbered events in the sequence.”¹³ This shows that the human tendency is to entrain to a binary rhythm. Given the prevalence of binary meters in western music (Fig. 1), it can be assumed that those with backgrounds largely in western music may be biased towards this binary default and may find it harder to entrain to other rhythms, as opposed to those with no western music background.

This was shown in the results of the experiment, where there was a slightly negative correlation between success in the control task and success in the 5-beat cycle (Fig. 8a). This may be because those for whom the march was most easy to entrain to (those with more western music experience and statistical learning) are exactly the people for whom non-binary, non-symmetrical meters may be most unfamiliar and cognitively challenging due to the binary default.

5.4 Further Experiments

In order to further study both the musical and cognitive reasons for this rhythmic phenomenon, there should be more experiments using both a larger number of participants and equipment that can measure brain activity. 29 participants were used in my experiment, so a larger number could provide more diverse or more accurate results. Additionally, another experiment could be asking one to entrain to the five- and seven-beat cycles and watch their neurological activity. This would greatly improve the understanding of how cognition differs between those two cycles and could provide more conclusive results. Furthermore, observing neurological functioning would provide great benefit to this type of study. Possibly, a positron emission tomography (PET) scan could be taken while playing the five- and seven-beat cycles, focusing on the pattern processing areas of the brain, the right cortical areas, tempo processing areas, posterior insula, postcentral gyrus, and somatosensory related areas.¹⁴ Differences might be observed in these neural components and could be further analyzed to find rhythmic perceptual differences.

13 Huron, David. *Sweet Anticipation: Music and the Psychology of Expectation*. MIT Press, 2008, 195–196.

14 Thaut, Michael H et al. “Human brain basis of musical rhythm perception: common and distinct neural substrates for meter, tempo, and pattern.” *Brain sciences* vol. 4,2 428–52. 17 Jun. 2014, doi:10.3390/brainsci4020428

6.0 Conclusion

When comparing human perception and execution of a five- and seven-beat rhythmic cycle, participants are likely able to entrain to all aspects of the seven-beat cycle better than to the five-beat cycle. This, and other observations from the study, was not due to the music chosen, but likely due to various cognitive factors, such as the music's inter-onset interval and the binary default in humans. I hope that more factors for this anomaly, both musical and cognitive, will be further studied and explored.

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Science in Women's Cosmetics of 17th Century Europe

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Author Background: Sarah Liu grew up in China and attended Kent School in Kent, Connecticut in the United States. Her Pioneer research concentration was in the field of History of Science and titled "The Scientific Revolution in Early Modern Europe."

Abstract

My paper focuses on female-authored cosmetic recipes in 17th century Europe, mainly England and France. I closely analyzed three main primary sources: *The Trotula*, *The Accomplish'd Ladies Delight in Preserving, Physick, Beautifying and Cookery* by Hannah Woolley (referred to as *The Accomplish'd* below) and *La Chymie Charitable et Facile en Faveur des Dames* by Marie Meurdrac. Through analyzing these recipes, I have found many scientific elements in them, such as the experimental language, the knowledge of botany, chemistry and biology, the science of cookery and medicine as well as familiarity with female anatomy and mentality. In this paper, I aim to focus on an area (cosmetics) that does not receive much attention from historians studying early modern European recipe books. I also hope to empower women today, who remain underrepresented in the STEM workforce, by demonstrating that women in early modern Europe practiced science albeit their inferior position in society.

Historical Context and Historiography

The Scientific Revolution unfolded in Europe roughly between the 15th and 18th century. The period began with Nicholas Copernicus (1473–1543)’s bold claim that the Earth moved in circular paths around the Sun.¹ To support Copernicus’ heliocentric cosmos, a series of new discoveries took place: Johannes Kepler developed his three major laws of planetary motion; Galileo Galilei devised new theories of motion that would accommodate a moving earth; Sir Isaac Newton, with his mathematization of nature, displaced the Aristotelian Universe and laid the foundation for classical mechanics.² These groundbreaking achievements, however, do not fully demonstrate the impact of the Scientific Revolution. Despite it being named a “revolution,” it was not a sudden eruption prompting a radical change; rather, it was an overall shift in belief system. Science rose up as an autonomous discipline and replaced Christianity as the focal point of European civilization. The Europeans went from considering Earth, Water, Air and Fire as the four ultimate components of the Universe (Aristotle) to a mechanical view of the world. The newly developed experimental method stressed the “how” rather than the “why”.³ Scientific Societies, such as the Royal Society of London for Improving Natural Knowledge (1662) and l’Académie des Sciences of Paris (1666), emerged as platforms for natural philosophers to gather, discuss, examine and validate their theories.⁴ With the invention of the Gutenberg printing press in Europe around 1450,⁵ publishing and mass production of books also replaced the old practice of hiding new discoveries.

Along with the Renaissance, the Scientific Revolution marked the transition from the Middle Ages to the Early Modern period (1500–1800) and fostered the Enlightenment.⁶ However, it is noteworthy that this movement was extremely exclusive—only a select group of elite men participated. Women in particular were restricted to the domestic sphere and did not have access

1 Robert A. Hatch, “The Scientific Revolution,” *The Scientific Revolution*, accessed September 17, 2020, <http://users.clas.ufl.edu/ufhatch/pages/03-Sci-Rev/SCI-REV-Teaching/03sr-definition-concept.htm>.

2 Hatch, “The Scientific,” *The Scientific Revolution*.

3 Stephen G. Brush and Margaret J. Osler, “Scientific Revolution,” *Britannica Concise Encyclopedia*, last modified August 20, 2019, <https://www.britannica.com/science/Scientific-Revolution>.

4 Hatch, “The Scientific,” *The Scientific Revolution*.

5 History.com. “Printing Press.” HISTORY. Last modified May 7, 2018. Accessed October 6, 2020. <https://www.history.com/topics/inventions/printing-press#:~:text=Goldsmith%20and%20inventor%20Johannes%20Gutenberg,use%20commercially%3A%20The%20Gutenberg%20press>

6 Brush and Osler, “Scientific Revolution.”

to any form of scientific knowledge or education. Despite their inferior position in society, a group of female intellectuals conducted science in their designated place—the household. An important segment of their work takes written form in recipe books, which widely circulated 16th and 17th century Europe. These recipe books contain three main sections: cookery, domestic medicine and cosmetics. Among these sections, cosmetics depended the most upon women, both as creators and users of the product.

There have been many historiographical arguments surrounding these recipe books, approaching them (the recipe books) from different viewpoints. A considerable number of historians examine the recipes carefully, but very few of them analyze the cosmetics section in great depth. Sarah Gordon in her article “Chemistry, Medicine, and Beauty on the Edge: Marie Meurdrac,” for example, looks closely into the cooking and medicinal recipes in *La Chymie Charitable et Facile en Faveur des Dames (La Chymie)* by Marie Meurdrac but only briefly lists out the cosmetic treatments.⁷ Elaine Leong and Wendy Wall in their books both identify the exchange and writing of recipe books as a form of social practice in early modern England.⁸ *Ecofeminist Approaches to Early Modernity* by Jennifer Munroe and Rebecca Laroche adopts a different perspective: it uses the written recipe books to study the authors' attitude toward nature.⁹

Some articles or books pay more attention to the context of the published recipes rather than their actual content, such as “Marie Meurdrac—First Lady of Chemistry?”. The article argues that Meurdrac was the first woman to practice and write about chemistry, with confirmation from the French Académie des Sciences. It summarizes Meurdrac's work as being related to chemistry but mentions nothing specific from it.¹⁰ *Women and Domestic Medicine 1500–1700*, a book edited by Lynette Hunter and Sarah Hutton, examines the earliest three books on domestic science and medicine of female authorship (by Elizabeth Grey, Alethea Talbot and Queen Henriette

7 Sarah Gordon, “Chemistry, Medicine, and Beauty on the Edge: Marie Meurdrac” *Women on the Edge in Early Modern Europe*. (Amsterdam: Amsterdam University Press, 2019).

8 Elaine Leong, “Recipes, Households, and Everyday Knowledge.” In *Recipes and Everyday Knowledge: Medicine, Science, and the Household in Early Modern England*. (Chicago: University of Chicago Press, 2018); Wendy Wall, *Recipes for Thought: Knowledge and Taste in the Early Modern English Kitchen*. (Philadelphia: University of Pennsylvania Press, 2015).

9 Jennifer Munroe and Rebecca Laroche. *Ecofeminist Approaches to Early Modernity*. (1st; First; ed. New York: Palgrave Macmillan, 2011).

10 Lloyd Bishop and Will S. DeLoach. “Marie Meurdrac-First Lady of Chemistry?”. (*Journal of Chemical Education* 47 (6): 448, 1970).

Maria respectively, all members of the aristocracy). In section four of the book, Hunter argues that these aristocratic women turned a traditional pursuit of women into a leisure pursuit, and that in doing so they contributed to the movement into science as natural philosophy.¹¹ One possible way to build onto Hunter's argument is by studying recipe books by authors who were not part of the nobility, such as Hannay Woolley and Marie Meurdrac. Like many of her counterparts mentioned above, Hunter discusses household science, including food and medicine, but not cosmetics.¹² To gain a broader understanding of female practitioners of science in early modern Europe, other historical works about women and science were also consulted. *Daughters of Alchemy: Women and Scientific Culture in Early Modern Italy*, for instance, introduces female figures in Italy in the 15th and 16th centuries such as Caterina Sforza and Lucrezia Marinella.¹³ The book, however, is not particularly useful to this essay since it focuses on a specific location (Italy) and an earlier time frame.

Based on these different historical arguments and analysis, cosmetics (mostly for women and created by women) during the Scientific Revolution in Europe is largely overlooked as a site of science. Why does this gap in academia exist? Is it because cosmetics is completely unrelated to science, as broad and encompassing a field as it is?

To answer these questions, three recipe books from early modern Europe were selected to be analyzed: *The Trotula*, *The Accomplish'd Ladies Delight in Preserving, Physick, Beautifying and Cookery (The Accomplish'd)* by Hannah Woolley and *La Chymie Charitable et Facile en Faveur des Dames* by Marie Meurdrac. During the process of selection, other recipe books, such as the *Cookery and Medicinal Recipes of the Granville Family* (a manuscript), were also reviewed. However, the three specific sources listed above were chosen because while each is unique, they are similar in many ways: they are all of female authorship (though inconclusive, the cosmetics section in *The Trotula* is likely written by a woman, as will be analyzed), they all aimed at a female audience and contain a comprehensive section on cosmetics.

The Trotula is a medieval compendium of women's medicine. Though it was created centuries earlier than the other two recipe books mentioned above, it reached its popularity in western Europe during the early modern

11 Lynette Hunter and Sarah Hutton. *Women, Science and Medicine 1500–1700: Mothers and Sisters of the Royal Society*. (Sutton Pub, Thrupp, Stroud, Gloucestershire, 1948–1997).

12 Hunter and Hutton, "Women, Science".

13 Meredith Ray. *Daughters of Alchemy: Women and Scientific Culture in Early Modern Italy*. (Cambridge, Massachusetts: Harvard University Press, 2015).

period.¹⁴ Originally written in Latin, *The Trotula* was translated by many, Monica Green being one of them. In the preface of her book, Green provides more context on the compendium.

“Trotula” is said by some to have lived in the 11th or 12th century and is alleged to have written the most important book on women's medicine in medieval Europe—*On the Diseases of Women*. Trotula is also alleged to have been the first female professor of medicine, teaching in the southern Italian town of Salerno . . . The word “Trotula” was originally a title instead of an author's name. *The Trotula* was indeed the most popular assembly of materials on women's medicine from the late 12th through the 15th centuries. Written in Latin and so able to circulate throughout Western Europe . . . the Trotula had also by the 15th century been translated into most of the western European vernacular languages, in which form it reached an even wider audience. Surprisingly, for all its historical importance this work exists in no printed form that can be reliably be used by students and scholars. The Latin Trotula was edited for publication only once, in the sixteenth century . . . and the only modern translations available are based on this same Renaissance edition.¹⁵

In terms of the authorship, Green indicates that “*On the Condition of Women*” and “*On Women's Cosmetics*” were anonymous and “*On Treatments for Women*” was attributed even in the earliest manuscripts to a Salernitan woman healer named Trota.¹⁶

The specific identity of the author, however, is up for debate among historians. Betty Kelves, for example, asserts that the *Trotula* texts were written by three different male authors instead of a female heroine and that only a fragment of one of the works can be attributed to the real Trota.¹⁷ She also argues that the author of the medical recipes in *The Trotula* was ignorant of female anatomy,¹⁸ which would contradict Green's claim that “*On Treatments for Women*” belonged most likely to the real Trota, since it is unlikely that a female physician was unfamiliar with her own body.¹⁹

14 Green, Monica Helen. *The Trotula: An English Translation of the Medieval Compendium of Women's Medicine*. Philadelphia, PA: University of Pennsylvania Press, 2002. Digital file.

15 Ibid.

16 Ibid.

17 Kelves, “Scientific VIEW”.

18 Ibid.

19 Green, *The Trotula*.

The second primary source consulted in this paper, *The Accomplish'd Ladies Delight in Preserving, Physick, Beautifying and Cookery*, is one of the many works of Hannah Woolley, an English writer who published early works on household management. It is representative of a standard recipe book with three sections: cookery (candyng and preserving), medicine and beautifying. See below the cover page of her book with an image of the domestic space.

La Chymie Charitable et Facile en Faveur des Dames is a French source by Marie Meurdrac, arguably the first female chemist.²⁰ It is used alongside the other two sources in English (*The Trotula* after translation by Monica Green in her book) because it contains knowledge of natural sciences not present in other contemporary recipe books, such as the procedures of the chemical processes and chemical symbols. The information is reasonably credible, since Meurdrac herself was well-respected as a female intellectual and practitioner of science. In its address to the readers, the bookstore calls Meurdrac “one of the most beautiful minds that appeared in our century.”²¹ The Doctors Regents from la Faculté de Paris attested that they found nothing but adherence to reason and experience in Meurdrac’s *La Chymie*, signed Blondel in Paris in October of 1672. It is worth noting that Blondel is a male name in French, and male recognition of scientific work by females was extremely rare then. Meurdrac’s work is also unique in that while it is more “scientific” than the other works, it also contains more superstitious ideas, such as using a young girl’s pee as an ingredient.²²

To better understand the position of cosmetics in the scientific world, the specific sections in the three recipe books are compared to other established works of science. The conclusions are presented below.

Cosmetics in the Scientific Canon

The cosmetics sections in the three recipe books (especially Meurdrac’s *La Chymie*) involve specific aspects corresponding to those in two other major works of science during the Scientific Revolution: *On the Revolutions of the Heavenly Spheres* by Nicholas Copernicus and *The Somnium* by Kepler. Starting with the preface, Meurdrac, Woolley and Copernicus all dedicated their work to someone of a superior position: Meurdrac to “Madame la

20 Bishop and DeLoach, “Marie Meurdrac”.

21 Meurdrac, *La Chymie*.

22 Meurdrac, Marie. *La Chymie Charitable Et Facile En Faveur Des Dames*. 2nd ed. Lyon, France: Chez Jean Baptiste Deville, ruë merciere, à la Science, 1680. Digital file.



Figure 1.

Cover Page of *The Accomplish'd Ladies Delight in Preserving, Physick, Beautifying and Cookery* by Hannah Woolley. From Oberlin College Library.

Comtesse de Guiche,²³ a French noblewoman, Woolley to the noble ladies in general²⁴ and Copernicus to “His Holiness, Pope Paul III.”²⁵ Though there is no preface in *The Trotula*, we can infer from its content (especially the ingredients used) that it is also aimed at a specific audience of nobility (This will be analyzed in the botany section below).

Furthermore, both Meurdrac and Copernicus challenged existing beliefs with their ideas; even the phrases they used to express themselves in the foreword are identical. Meurdrac claims that it took her two years to decide whether or not to publish her work, and that doing so was a “combat”²⁶ for her, while Copernicus confesses that “I debated with myself for a long time whether to publish the volume which I wrote to prove Earth’s motion.”²⁷ They then both anticipate potential negative reactions: Meurdrac is well aware that “men always despise productions coming from the mind of women”²⁸ while Kepler realizes that “as soon as some people hear that in this volume . . . [he]

23 Meurdrac, *La Chymie*.

24 Woolley, *The Accomplish'd*.

25 *Nicholas Copernicus Complete Works, On the Revolutions Minor Works*. Translation and commentary by E. Rosen and E. Hilfstein (Baltimore: John Hopkins University Press, 1992).

26 Meurdrac, *La Chymie*.

27 Copernicus, *On the Revolutions*.

28 Meurdrac, *La Chymie*.

ascribe[s] certain motions to the terrestrial globe, they will shout that [he] must be immediately repudiated together with this belief.”²⁹ Indeed, what the two of them did was extremely radical in their time—Copernicus argued for Earth’s motion when it was believed for centuries to be at rest and in the center of the universe, and Meurdrac taught and practiced science as a woman in a period where women were denied access to science and knowledge in general. Even though Meurdrac and Copernicus seem to share no correlation, they both had enough character to defy the norm.

La Chymie can also be compared to Kepler’s *The Somnium*. One possible reason why science in cosmetics is overlooked (a question raised previously) is the superstition in the recipes. However, this element cannot render cosmetics un-scientific because it is found in other established works of science. Both *La Chymie* and *The Somnium* contain a juxtaposition of superstitious beliefs and scientific truth. Let us begin by looking at *La Chymie*. On one hand, there are many elements of folk medicine in the recipes, such as the instruction to “wash your face in the wane of the moon,” “rub the lips with the sweat behind your ears to make them smooth and well colored,” “anoint the face with the blood of a Hare or a bull and this will take away the freckles and make the skin smooth” and even to “use the pee of a young girl between the age of 9–10” as an ingredient.³⁰ None of these have real scientific proof behind them. However, on the other hand, all of these superstitious instructions are accompanied with distillation, a legitimate process often used in scientific experiments (especially chemistry). We also should not forget that Meurdrac explained distillation in great detail at a time when the entire field of chemistry was rather new to the world. The French Académie des Sciences even confirmed her to be the earliest female author of chemistry.³¹ In *The Somnium*, imaginative and supernatural elements are also juxtaposed with scientific truth. The mother of the narrator in the story is a witch that can summon the “Daemons,” semi-divine beings of Classical Greek mythology. The creatures that inhabit Subvolva and Privolva, two terms referring to two parts of the moon, have short life, rapid growth and massive size. All of these are based on Kepler’s imagination. Meanwhile, there exist many scientific truths in *The Somnium* such as how the size of the Earth varies from the perspective of its moon (Levania).³²

29 Copernicus, *On the Revolutions*.

30 Meurdrac, *La Chymie*.

31 Bishop and DeLoach, “Marie Meurdrac”.

32 Johannes Kepler, *Somnium (The Dream)*, trans. E. Rosen (n.p.: Kepler’s son Ludwig Kepler, M.A. Candidate for the Doctorate in Medicine, 1634).

With the conclusion from above that cosmetic theories are at least similar to scientific ideas and works, a subsequent question can now be raised: What are, if any, some of the scientific elements uniquely found in cosmetics? Some sub-questions surrounding this main one include how the body (primarily the female body) was used as a site of science and what the relationship between women and science was from studying cosmetics. These questions will be answered in the remaining portions of this essay.

The Scientific Elements in Cosmetics

There is an experimental nature to the cosmetics recipes. Similar to how the cooking recipes and medical cures occupy the kitchen and household, cosmetics use the body (specifically that of a female) as a site of scientific experiment. Let us begin by looking at the experimental language itself. In *The Trotula*, the word “if” is used multiple times for hypothetical situations, with solutions provided accordingly: “if it happens that the skin is burned from this depilatory, take . . .,” “if the depilatory should be too thick, put in fresh water to thin it,” “if she cannot have this, let her simply wash herself well.”³³ For one of the depilatory recipes, the author advises the female user against “rub[bing] herself because her limbs will be excoriated.”³⁴ The conditional statements constructed by the “if” and the instructions suggest that the author had adequate experience with the impact of these recipes and used the female body as a site of science to test the impacts.

Similarly, Marie Meurdrac mentions in *La Chymie* that the queen of Hungary was also a practitioner of science and tested the written form of her recipe “Eau de la Reine de Hongrie.” Meurdrac herself had enough experience to know that distilled water “will not preserve” unless when “put under the sun.” She even used her own body as a site of science, claiming to have “healed and recovered [her] forces” after trying the queen’s recipe.³⁵ In her work *The Accomplished Ladies Delight*, Hannah Woolley uses a more direct term “a sure and tried experiment” to show that her conclusion “strawberry leaves clean the teeth and gum” originated from experiments. Like the other two authors, she was also able to predict that the distilled water for the “Virgins Milk” recipe will “be like milk.”³⁶ This conclusion requires not only

33 Green, *The Trotula*.

34 Green, *The Trotula*.

35 Marie Meurdrac, *La Chymie Charitable Et Facile En Faveur Des Dames*, 2nd ed. (Lyon, France: Chez Jean Baptiste Deville, rue merciere, à la Science, 1680), digital file.

36 Woolley, Hannah, Adam Matthew Digital, and Bodleian Library. *The Accomplish'd Lady's Delight in Preserving, Physick, Beautifying, and Cookery: Containing*. London:

several tests of the recipe on Woolley's part but also strict observation and judgement by the readers and users (mostly female). After all, they must be able to compare the form of the product with that of milk and assess the similarity subjectively.

In addition to the authors, the users of the recipes also conducted scientific experiments. The author of *The Trotula* asks his/her users to "test" a recipe of depilatory "with a feather to see if it is sufficiently cooked," the word "test" creating a commanding tone unlike the conditional statement with "if's" as mentioned previously. Many other instructions in the book also require a certain degree of judgement on the users' part; for example, the two instructions to use "well-cooked egg yolks" and to "let them (the ingredients) remain there until the exterior shell is like the interior skin of the egg" both require close observation regarding the subtle changes of the ingredients.³⁷ Meurdrac gives similar directions such as "distill it until there rests no more humidity at the bottom of the vessel." For one of her "waters," she gives no specific instruction and simply asks the users to "serve based on one's own judgement."

The users were not only the practitioners but also the subjects of the experiments. Since cosmetics use the body of the practitioner directly as a site of experiment, they have a subjective nature. Many of Meurdrac's recipes, for example, are specific and personal. According to her, women need to choose their own waters and ointments because "those that work for one person may not work for someone else."³⁸ Woolley also gives instructions that correspond to this advice, such as "hold them within the oats as hot as you can endure them" and "wash your hands in it as hot as you can suffer it," both depending completely on the individual user.³⁹

The concern with the users' safety in cosmetics is similar to the safety procedures in a scientific experiment. The authors of the three recipe books took into consideration the well-being of the audience, both as practitioners and subjects. *The Trotula's* author, to begin with, informs his/her audience to "take care not to touch the eyebrows" or "take care not to get it in the eyes" with certain treatments. Here the audience are conducting the experiments.⁴⁰

Printed for B. Harris and are to be sold at his shop., 1675. Adam Matthew Digital, and Bodleian Library.

37 Green, *The Trotula*

38 Meurdrac, *La Chymie*.

39 Hannah Woolley, *The Accomplish'd Lady's Delight in Preserving, Physick, Beautifying, and Cookery: Containing* (London: Printed for B. Harris and are to be sold at his shop., 1675), Adam Matthew Digital, and Bodleian Library.

40 Green, *The Trotula*.

Meurdrac, on the other hand, is concerned with the audience's safety when they serve as the subjects of the experiments. She added an entire section dedicated to warning her audience against potential dangers and accidents when they apply things to their faces. Among these pieces of advice, one is against using mercury and sublime because they lead to diseases sometimes incurable and another is to be "careful to put in as little as possible of camphor, because it will cause women to lose teeth and result in inflammation."⁴¹ The users of the cosmetics recipes across the three works were all greatly involved in the experimental processes, as they created and tested the products.

Furthermore, the tools and units in the recipes are also similar to those in scientific experiments. The "crucible" is a tool used in nearly every one of Meurdrac's recipes.⁴² It is a ceramic or metal container in which metals or other substances may be melted or subjected to very high temperatures, often used in chemistry.⁴³ Like in the experiments, Meurdrac has strict demands for the tool used in her recipes. She asks her readers to "use a white laundry towel" to apply one recipe and "use a hemp cloth" for another one. She also measures her ingredients with precise units such as "three pints of cow milk" and "one ounce," corresponding to units of different materials in experiment procedures.⁴⁴ With the standardization of testing, they (the procedures) are no longer conjectures but repeatable, scientific processes.

Botany

In addition to their similarity to scientific experiments, these recipes contain heavy use of plants and botanical knowledge. Before analyzing the effects of these plants, it is useful to look at their origins. Those in the *Trotula* recipes, for example, spread across five different continents—Africa, America, Asia, Australia/Oceania and Europe—and more than 10 different countries.

Even though the author of *The Trotula* was most likely based in Europe, he/she managed to use henna, a tropical shrub from northern Asia, Africa and Australia,⁴⁵ and galangal, a spice native to Southern Asia.⁴⁶ There are

41 Meurdrac, *La Chymie*.

42 Meurdrac, *La Chymie*.

43 *Oxford Dictionaries*, s.v. "crucible," accessed August 22, 2019.

44 Meurdrac, *La Chymie*.

45 Encyclopaedia Britannica, "Henna," Britannica, accessed October 9, 2020, <https://www.britannica.com/plant/henna>.

46 Alina Petre, "Galangal Root: Benefits, Uses, and Side Effects," Healthline, last modified November 14, 2019, accessed October 9, 2020, <https://www.healthline.com/>



Figure 2.

Geographical Origins of the plants. Created with Google Maps.

especially more plants found in the Muslim regions, such as cinnamon from Sri Lanka, galbanum yielding plants from Iran, nutmeg from Indonesia, and galangal from Java, an island of Indonesia. Perhaps this geographical concentration can be attributed to the Arabic origin of some of the recipes. He/she (the author) refers to the “Saracen women” as his/her source of information multiple times, once with “the women of the Saracens dye their faces in this manner” and the other “I saw a certain Saracen woman liberate many people with this medicine.”⁴⁷ In Medieval Latin literature, “Saracen” referred to anyone who practiced the religion of Islam. After later spreading into Western Europe, the term “has survived until modern times.”⁴⁸

Moreover, the origin of the plants has a strong correlation with the author’s intended audience—the nobility. Not only does he/she directly point out that many of the recipes were “an ointment for noblewomen,” but certain ingredients are luxurious in nature, such as “bear fat” for helping the hair grow, “French soap” for washing the face on a daily basis and the frequent use of red and white wine.⁴⁹ These all point to the wealth and social status of the potential users. With these privileges, they (the users) likely had more access to plants from different countries, and even continents, than the general public.

nutrition/galangal-root#:~:text=Galangal%20root%20is%20a%20spice,plants%20of%20the%20Zingiberaceae%20family

⁴⁷ Green, *The Trotula*.

⁴⁸ The Editors of Encyclopaedia Britannica, “Saracen,” Britannica, last modified September 17, 2008, accessed October 9, 2020, <https://www.britannica.com/topic/Saracen>.

⁴⁹ Green, *The Trotula*.

Woolley's *In Preserving* includes plants quite different from those found in *The Trotula*. Some examples of what Woolley used frequently are Turmeric, bark of the barbary tree, hyssop-roots, sowbread, fumitories and the sap from the birch tree, all ingredients unique to her work. Her remark that the birch tree sap "will dissolve pearl, a secret not known to many" highlights her exclusive botanical knowledge that can be narrowed down to an unusual use of the sap of a specific type of tree. Despite few overlaps in specific plants between her recipes and those in *The Trotula*, there are several similarities in a broader aspect. First, Woolley's plants also come from different continents, spreading all the way from South America to Southeast Asia. Second, her audience also belonged to the upper class, as in her foreword she addresses them as "Ladies" and herself as "your humble servant and admirer." Finally, Woolley also cites different sources of information in her work, including "a traveler who hath cured himself thereby," "an excellent beauty-water used by the D. of C.," "another [recipe] by an approved author" and "an excellent beautifier for the face used by the Venetian ladies."⁵⁰

The global aspect of cosmetics is an aspect shared by other works of science. To begin with, the global origins of the ingredient plants suggest that cosmetics recipe collections and writings are based on a process of travelling and information exchange. This network enabling science is also found in Newtonian philosophy, as Simon Schaffer argues in his book *Newton on the Beach: The Information Order of Principia Mathematica*. According to him, Newtonian natural philosophy actually depended upon the network of trade during the commercial revolution of Georgian Britain, contrary to the belief of many that Newton worked in solitude. Schaffer cites specific examples such as how Newton alone did not make the observations of the tidal waves and instead referred to the work of other scientists.⁵¹ Similarly, *The Trotula*'s author, Meurdrac and Woolley also incorporated recipes used by others. Since Newton is recognized as one of the greatest scientists ever lived, it is reasonable to consider the cosmetics recipes scientific for being similar to his work.

Slave medicine is another form of science that depended on a global network. Londa Schiebinger in her book *Secret Cures of Slaves* closely studies slave medicine from the late 18th to 19th century and points out that many cures actually had Amerindian origins, such as "a leaf of tobacco for treating head-ache," in which "tobacco" originated in the Americas.⁵² Likewise, many

50 Woolley, *The Accomplish'd*.

51 Simon Schaffer, "Newton on the Beach: The Information Order of Principia Mathematica." (*History of Science* 47 (3): 243–276, 2009).

52 Schiebinger, Londa L. *Secret Cures of Slaves: People, Plants, and Medicine in the Eighteenth-Century Atlantic World* (Stanford, California: Stanford University Press, 2017).

plants used in the three European cosmetics recipe books have Asian, African or American origins. Though slave medicine may not be as well acknowledged as Newtonian philosophy, it is still treated as a work of science, at least in Schibinger's book. Therefore, the fact that the cosmetics recipes are comparable to it (slave medicine) again renders them scientific.

Chemistry and Biology

Unlike *The Trotula's* author and Woolley, Meurdrac used less plants and instead relied on chemistry. Nearly all of her recipes are "waters" resulting from the chemical process of distillation (which she introduces in great detail in the first few chapters of her book), such as distilled flowers, "a water of life distilled four times" (Hungarian Queen's water) and even water distilled from animal flesh or bone.⁵³ Her recipes indicate a greater familiarity with chemical knowledge, both in regard to herself and her audience. In order to practice Meurdrac's recipes, they (the audience) must have a basic grasp of the chemical processes and be able to conduct experiments in the household. Meurdrac also made great use of chemical compounds, such as quicksilver (liquid metal mercury) and borax (a white mineral in some alkaline salt deposits).⁵⁴ This strong connection with natural science (chemistry) distinguishes Meurdrac's *La Chymie* from *In Preserving* and *The Trotula*.

These recipes are not just random collections of plants from all over the world or chemical compounds. With our knowledge in biology and chemistry today, we are able to discover that there is actually scientific truth behind the ingredients, especially with the ones used across different works and authors. To begin with, sweet almond oil is used in the skin care recipes of all three books. Providing both health and beauty benefits, it is rich in vitamin E, vitamin A, monounsaturated fats (70%), protein, potassium and zinc, which all protect the skin and hair. It is especially effective for moisturizing sensitive and dry skin and making a hair mask.⁵⁵ Even though *The Trotula's* author, Meurdrac and Woolley probably were not familiar with the oil's biological components, they did realize, quite accurately, that it was good for the skin. The fact that they specifically used "sweet" almond oil instead of bitter almond oil (used to provide scent and flavor) also indicates their awareness

53 Meurdrac, *La Chymie*.

54 Meurdrac, *La Chymie*.

55 Buckler's Team, "The Many (So Many!) Benefits of Sweet Almond Oil for Your Skin," Buckler's, last modified January 23, 2017, accessed August 22, 2019, <https://bucklersremedy.com/blogs/the-dirty/the-many-so-many-benefits-of-sweet-almond-oil-for-your-skin>.

of the differences in effect. Without a grasp of established scientific truth, the knowledge of these authors likely came from testing and experimenting with different materials.

Another popular ingredient for skin care in the recipes is animal grease, including that of bears, capons, dogs, veal, etc. Animal grease is composed of fatty acids and fat-soluble vitamins, such as vitamin A, D, E, and K2, all excellent for the skin.⁵⁶ Rosemary is the most commonly used aromatic plant, and its nutrients can help protect skin cells from damage often caused by the sun and free radicals. Also, since it has natural antiseptic properties, it is a superior disinfectant for skin and hair.⁵⁷ The next one is borax, a chemical compound also known as sodium borate. It continues to be used in cosmetics products today, often as an emulsifier, buffering agent or preservative for moisturizing products, creams, shampoos, gels, lotions, bath bombs, scrubs and bath salts.⁵⁸ The final one, and possibly the most popular one in many different recipes and books for cosmetics, is the white of eggs. Like borax, it is still used for beautifying purposes today, because it contains albumin, a simple form of protein that helps tighten pores and clear blackheads.⁵⁹ It is, however, important to avoid misuse of egg white, such as choosing unsafe sources of eggs, because it could lead to potential risks such as infection and egg intolerance.⁶⁰ After studying their components and uses, it is clear that these ingredients all contribute to beautifying and cosmetics from a scientific perspective, many of which continue to serve the same purposes today as they did in those recipe books written centuries ago.

Finally, camphor is used frequently in both *The Trotula* and *La Chymie*. Both of these authors made correct use of “camphor”: the author of *Trotula* includes it in an ointment for face⁶¹ and Meurdrac in a “toile cirée admira-

56 Nedahl Stelio, “How to Eat Collagen for Naturally Younger Skin,” stuff, last modified December 18, 2015, accessed August 22, 2019, <https://www.stuff.co.nz/life-style/well-good/teach-me/75266716/>.

57 Kristin Collins Jackson, “5 Rosemary Benefits That Will Keep Your Pits Fresh, Hair Silky, and Skin Clear,” Bustle, last modified July 19, 2014, accessed August 22, 2019, <https://www.bustle.com/articles/32175-5-rosemary-benefits-that-will-keep-your-pits-fresh-hair-silky-and-skin-clear>.

58 Erica Cirino, “Is Borax Toxic?,” healthline, accessed August 22, 2019, <https://www.healthline.com/health/is-borax-safe>.

59 Joyce Kong, “How Eggs Can Help Your Skin Look Damn Good,” Refinery29, last modified November 20, 2014, accessed August 22, 2019, <https://www.refinery29.com/en-us/eggs-beauty-ingredient>.

60 Kristeen Cherney, “Why Egg White for Your Face Is a Bad Idea,” healthline, <https://www.healthline.com/health/beauty-skin-care/egg-white-for-face#should-you-use-them>.

61 Green, *The Trotula*.

ble”⁶² (an oilcloth from direct translation) for the face. Camphor is still used in lotions and creams today to treat skin conditions, relieving skin irritation and itchiness. The use of camphor, however, is rather controversial. Like most other materials, correct usage for camphor is crucial and it is toxic when overused or taken internally.⁶³ It is also intriguing how Meurdrac reminds her audience (mentioned previously in this essay) to “put in as little as possible of camphor”⁶⁴ directly on the face in the foreword of her section on compositions for facial beautification while she uses it as an ingredient in the oilcloth recipe. This paradox cannot necessarily be explained at present, but it is definitely worth further investigation.

Aside from the common ingredients, the unique ones also prove to have scientific uses. *The Trotula* in particular includes many plants and substances not used in the other two works. For example, the users are instructed to “take populeon with rose or violet oil or with juice of houseleek, and mix them until the heat is sedated” when “it happens that the skin is burned from this depilatory.”⁶⁵ This is an accurate use of houseleek, since it is a non-flowering plant whose leaf is used to make medicine, and some apply it directly to the skin for burns.⁶⁶ A similar example is the use of the plant henna for “coloring the hair so that it is golden.”⁶⁷ Like houseleek, its leaves are also used for medicine. In manufacturing, henna is used in hair dyes, cosmetics, and as a dye for nails, hands and clothing.⁶⁸ Clearly, it has served its purpose in cosmetics since early modern Europe. Most of the other plants also have medicinal uses. For the aroma of the hair or skin, there are aromatic resins obtained from the tree, like galbanum, mastic, frankincense, cinnamon, nutmeg and clove. Watercress, galangal and elecampane are three other ones often used in herbal medicine. *Trotula*’s author relied on his/her botanical knowledge regarding the healing effects of these rare and exotic plants and successfully incorporated them into his/her recipes.

62 Meurdrac, *La Chymie*

63 “How to Use Camphor Safely: Benefits and Precautions,” healthline, <https://www.healthline.com/health/what-is-camphor>.

64 Meurdrac, *La Chymie*

65 Green, *The Trotula*.

66 “Houseleek,” MedicineNet, accessed August 22, 2019, <https://www.medicinenet.com/houseleek/supplements-vitamins.htm>.

67 Green, *The Trotula*.

68 “Henna,” WebMD, <https://www.webmd.com/vitamins/ai/ingredientmono-854/henna>.

Cookery and Medicine

The cosmetic recipes in the recipe books also include the science of cookery and domestic medicine. They (the cosmetic recipes) share various similarities with their cookery and medical counterparts, though many historians seem to believe otherwise by paying less attention to cosmetics. The use of animals (cats) in Hannah Woolley's work *Supplement to the Queen-Like Closet* is considered an element of science in the book *Ecofeminist Approaches to Early Modernity* by Jennifer Munroe and Rebecca Laroche. According to Munroe and Laroche, Woolley conducted a scientific experiment in the kitchen and used the cat and the nature in general as a tool to preserve health. This "use value" of nature in Woolley's medical recipes is no less illustrated in the cosmetics ones. *The Trotula*, for example, advises women to "take a green lizard," "remove its head and tail" and "cook it in common oil" if they "[wish] to have long and black hair."⁶⁹ Different parts of animals are also used: "goat's milk," "bear fat," "deer tallow," "steer or cow marrow" and "dove dung" (for the roughness of the face caused by the sun or the wind) are some examples.⁷⁰ Meurdrac distills animals like she does with every other ingredient. Her recipe for conserving and beautifying the face demands four feet of the veal (with the bone removed), a chicken (feet and innards) as well as four little dogs born just after one or two days. Another recipe for conserving and whitening the skin calls for a fat capon, and one of the waters even requires ivory.⁷¹ Woolley is no exception, using "the ashes of frogs burnt" and "the ashes of goats-dung mingled with oil" to increase hair.⁷²

Cosmetics recipes are also closely related to the cookery ones. Many of the ingredients in the beautifying recipes are food items. *Trotula* lists out "pomegranate" and "powder of oak apples" for blackening the hair.⁷³ Meurdrac continues this use of fruits with "a watermelon" mixed with sugar and a black baume. Her instructions to make a water for refreshing and widening the face include several edible ingredients: three pints of cow milk, three pints of white wine, two dozens of fresh eggs, the crumb of a small "pain de Chapitre," a handful of hulled barley, a piece of veal cut to small pieces and three or four onions of lilies.⁷⁴ If these ingredients were not all to be distilled, they could pass as a cooking recipe. Though Woolley was not a

69 Green, *The Trotula*.

70 Green, *The Trotula*.

71 Meurdrac, *La Chymie*.

72 Woolley, *The Accomplish'd*.

73 Green, *The Trotula*.

74 Meurdrac, *La Chymie*.

fan of food in cosmetics recipes, she did favor the use of whites of eggs like the other two authors.⁷⁵ Based on the above two paragraphs, we can see that the cosmetic section of the recipe books is not so different from the remaining two sections for it to be considered less scientific.

Female Anatomy and Mentality

The last scientific field of study (in modern terms at least) found in the cosmetics recipes is female anatomy. As we may recall from the introduction, Betty Ann Kelves asserts that the author of the medical recipes in *Trotula* is unfamiliar with female physiology. She refers to the example of “wandering womb,” an ancient (false) belief that women’s ills often come from the uterus moving about the body, as well as some treatments that put women in pain, such as balancing four humors (of Hippocratic medicine, will be explained further below) and excessive bleeding for irregular menstruation.⁷⁶ While determining the sex of *Trotula*’s author is not the goal of this essay, the cosmetics section does demonstrate a greater extent of familiarity with females. Instead of excessive bleeding, the cure for menstruation abnormalities is a “powder” with a certain type of juice that is supposedly “good for blood flow from the nose and for excessive menses.” The author also suggests “insert[ing] [the powder] by means of a pessary,” a small soluble block that is inserted into the vagina to support its inner structure, treat infection or deliver medications.⁷⁷ Since this tool is actually used for female medical purposes, the author is familiar with the female body to a certain degree, at least more than the one writing the medical recipes in *The Trotula*.

The audience also possessed knowledge of the female body, since the author provides no instruction on how to execute the process of insertion (by a pessary). An incorrect fitting could cause vaginal damage.⁷⁸ Another instruction to “put some of this confection in the opening which leads into the womb,” the “opening” being the vagina opening and the “womb” the uterus, is also correct anatomically.⁷⁹ The author deliberately adds the otherwise

75 Woolley, *The Accomplish’d*.

76 Betty Kelves. “Scientific VIEW: Catching the Scent of a Medical Mystery,” *Los Angeles Times* (1923–1995), H2. 1985.

77 Becky Young, “Pessary,” Healthline, last modified March 26, 2018, accessed October 9, 2020, <https://www.healthline.com/health/pessary#:~:text=A%20pessary%20is%20a%20prosthetic,out%20of%20its%20usual%20place.>

78 Young, “Pessary,” Healthline.

79 Green, *The Trotula*.

unnecessary phrase “which leads into the womb” to highlight his/her awareness of the construction of female body.

The demonstrated knowledge of female anatomy is impressive, given that there was limited understanding of female and male anatomy and their distinction in the 16th and 17th centuries. In the image of reproductive organs in Vesalius's *De Humani corporis fabrica Libri septem* (1543), the female procreational system is portrayed as a reversed version of its male counterpart.⁸⁰ Men and women were believed to be the same sex anatomically, thus sharing common organs.⁸¹ In the cosmetics section of *The Trotula*, however, the vagina and uterus are treated as unique female organs used for specific female needs, such as curing irregular menstruation and regaining (or faking) virginity. There is another aspect that sets the cosmetics recipes apart from the Vesalius' image. When it was produced, the image opened the discussion more to early modern cultural understanding of how sex worked, with topics such as female sexual desire and fertilization.⁸² In the cosmetics recipes in *The Trotula*, on the other hand, inserting things into the female body is for beauty and medical purposes instead of sexual ones.⁸³

The author of the cosmetics chapter in *The Trotula* was also aware of women's mentality. For one of the ointments, it is suggested that “if she is embarrassed to anoint her face during the day, let her anoint it at night.” This is not only concerning the user's safety or health, but also how she might feel. Regardless of the author's sex, he/she at least carefully considered the potential experience of the female user. He/she also indicates that “when she has to have sexual intercourse with anyone she hold these things under her tongue,” “these things” referring to laurel leaves and musk for eliminating bad breath.⁸⁴ Giving such detailed instructions on how women should act under which specific circumstance, the author is familiar with what is on the mind of his/her female audiences. Aroma was indeed of great concern to women: Woolley specifically wrote down a recipe for “a sweet-scented bath for the ladies”⁸⁵ when her other recipes do not specify the sex of the users in them.

Mentality is an important subject of discussion because it was linked to physical well-being in early modern Europe. The four humors and six

80 Lili Loofbourow, “What the 17th Century Can Teach Us about Vaginas,” *The Cut*, last modified September 19, 2014, accessed September 3, 2019, <https://www.thecut.com/2014/09/describing-a-vagina-the-16th-century-way.html>.

81 Loofbourow, “What the 17th,” *The Cut*.

82 Loofbourow, “What the 17th,” *The Cut*.

83 Green, *The Trotula*.

84 Green, *The Trotula*.

85 Woolley, *The Accomplish'd*.

non-naturals represent a concept of disease prevention based on Greek ideas by Hippocratic writers during the 4th century B.C., theories further developed by the Islamic writers, who termed it the “non-naturals.”⁸⁶ The six non-naturals are as follows: air, motion and rest, sleep and waking, things taken in (food and drink), things excreted, passions and emotions. This last element of the six “appears to have been a favorite topic for 17th century writers,” with the belief that “an excess of passion or emotion was thought to weaken the body.”⁸⁷ Certainly, the information and evidence found for women’s mentality in the cosmetics recipes are not as abundant and thorough as those for the other scientific fields, such as botany and chemistry. However, a brief discussion of mentality does provide an opportunity to open up the topic for further study and analysis.

Conclusion

Women’s cosmetics in early modern Europe contained many scientific elements: their similarities to canonical scientific works; their experimental nature; the knowledge of botany, chemistry and biology; the science of cookery and medicine; familiarity with female anatomy and mentality. These all demonstrate the engagement, dedication and intellectual prowess of the female practitioners of science.

Even today, women remain underrepresented in the STEM workforce (though to a much lesser degree than in the past). According to the data by National Girls Collaborative Project, women make up half of the total U.S. college-educated workforce but only 28 % of the science and engineering workforce. Women across the globe find themselves in similar positions: in the Republic of Korea, for example, only 17% of researchers are women and they represent merely 9% of those working in the field of engineering and technology.⁸⁸ A main reason for this disparity between the two sexes is that many still believe women to be less capable of these subjects than men.⁸⁹ In fact, many women themselves denounce their intellectual abilities. A report by *Science* based on results from experiments on 400 children suggests that

86 Louise Hill Curth, “Lessons from the Past: Preventive Medicine in Early Modern England” (*Medical Humanities* 2003; 29: 16–20).

87 Curth, “Lessons from the Past”.

88 “Just 30% of the World’s Researchers Are Women. What’s the Situation in Your Country?,” UNESCO, accessed September 17, 2020, <https://en.unesco.org/news/just-30-world%E2%80%99s-researchers-are-women-whats-situation-your-country>.

89 “Statistics,” National Girls Collaborative Project, last modified 2018, accessed August 22, 2019, <https://ngcproject.org/statistics>.

girls begin to consider themselves less smart than boys by the age of six.⁹⁰ At such a young age, girls are already under the influence of gender stereotypes. With this context, it is empowering to learn that women in early modern Europe, a period in history where they occupied an extremely inferior position in society and were deprived of opportunities, managed to practice science while preserving their beauty.

Some may argue that a field as stereotypically female as cosmetics fails to liberate women from traditional gender roles. However, the feminine nature of cosmetics further highlights the interrelation between women (and femininity) and science. Moreover, cosmetics represent a rather realistic picture of early modern European women's involvement with science—with almost no access to formal education or jobs outside of home, their primary concerns were household tasks (cooking and domestic medicine) and beautification. Within the sphere society confined them to, these women—authors and users of cosmetics recipes—did their best to challenge social norms by practicing science along with a small number of their male counterparts. Upon viewing and understanding the courageous endeavors of these women, we will hopefully regard cosmetics more seriously as a site of science and become aware of a longer history between women and science.

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90 Juliet Perry and Meera Senthilingam, "Girls Feel Less 'Smart' than Boys by Age 6, Research Says," CNN, last modified January 27, 2017, accessed September 17, 2020, <file:///Users/sarahliu/Downloads/fa20-math180-week02-recitation.pdf>.

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Comparative Analysis of Leonardo da Vinci's *Santa Maria Della Neve* and Huang Gongwang's *The Remaining Mountain*

Shuyu Chen

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Background Introduction

Landscape drawing is a typical theme in art in which natural scenery is the essential visual motif. Both *Santa Maria Della Neve* and *Dwelling in the Fuchun Mountains* are landscape drawings that show the artists' mastery of various drawings and their appreciation of nature. *Santa Maria Della Neve* is a drawing by one of the most prestigious Renaissance artists, Leonardo Da Vinci (1452–1519). Leonardo was born out of wedlock to notary Piero da Vinci and a peasant woman in Anchiano, Tuscany (now Italy). He apprenticed in the studio of Florentine painter Andrea del Verrocchio to further develop his talent in art. His sharp eyes, quick mind, and artistic skills made him a renowned genius in the craft of painting and in diverse fields of science. Leonardo drew *Santa Maria Della Neve* at the age of 21 when he had just finished his training in Florence.¹ The drawing depicts Montelupo Castle and the heart of the Arno Valley, where Leonardo spent a large amount of time during his formative years. This is a place that may have significantly influenced his personal development as an artist. *Landscape Drawing for Santa Maria Della Neve* is now part of the

1 David Alan Brown. *Leonardo Da Vinci: Origins of a Genius*. (New Haven: Yale University Press, 1998), 7.

permanent collection of Florence's Uffizi Gallery.²

Dwelling in the Fuchun Mountains is a scroll made by Chinese artist Huang Gongwang (黄公望, 1269–1354) in the Yuan dynasty. His original name was Lu Jian (陸堅), and he was a native of Changshu, Jiangsu, China. Gongwang came from an impoverished family and was orphaned at an early age. He was adopted by Huang Le, so he changed his surname to Huang according to the tradition of the time. After serving briefly as an official, he abandoned the thought of reaching higher ranks and studied Taoism in reclusion.³ In 1347, in his late seventies, Gongwang traveled to the Fuchun Mountains region and began drawing the handscroll *Dwelling in the Fuchun Mountains*, and finally finished it in his eighties. Hundreds of years later in the Qing dynasty, one of the collectors of this handscroll wanted to burn the drawing so that it would accompany him in his death, but his nephew quickly changed a different scroll into the fire and secretly saved *Dwelling in the Fuchun Mountains* from destruction. Due to the fire damage, the scroll was separated into two sections. The first part, *The Remaining Mountain*, is now in the Zhejiang Provincial Museum in Hangzhou, while the second part, known as *The Master Wuyong Scroll*, is in the National Palace Museum in Taipei.⁴



Figure 1.
Leonardo Da Vinci, Landscape drawing for Santa Maria Della Neve, 1473, Florence, Uffizi Gallery



Figure 2.
Huang Gongwang, The Remaining Mountain, 1347–1350, Hangzhou, Zhejiang Provincial Museum

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- 2 "The Diagnostic Campaign of the Opificio delle Pietre Dure on the First Landscape by Leonardo," Le Gallerie Deglie Uffizi, accessed August 4, 2019, <https://www.uffizi.it/en/magazine/diagnostic-campaign-%20first-landscape-leonardo-drawing-8p-opificio-pietre-dure>.
 - 3 "Chinese Landscape Example Huang Gongwang, Dwelling in the Fuchun Mountains," McMullen Museum of Art, Boston College, <https://www.bc.edu/sites/artmuseum/learn/resources/cao-jun/2.5a%20Reading%20%20Chinese%20Landscape%20Example.pdf>.
 - 4 "Landscape reunited: Huang Gongwang and Dwelling in the Fuchun Mountains," National Palace Museum, https://www.npm.gov.tw/exh100/fuchun/en_02.html

General Description

This paper comparatively analyzes the similarities and differences between *Santa Maria Della Neve* and *The Remaining Mountain* and further investigates why such similarities and differences exist based on the artists' cultural backgrounds and personal experiences. Even though the differences in the two drawings are apparent, given the disparity in the artists' demographics, culture, and time period, they effectively juxtapose with their unusual similarities that are yet unseen in other landscape artworks. It is intriguing to discover Leonardo Da Vinci uniquely breaking the Western landscape tradition and engaging in established Chinese art philosophy even before the two traditions began to interact and influence one another. The observed similarities between Leonardo's and Gongwang's works could trigger art historians to reconsider the idea that Western and Chinese landscape traditions were entirely unlike.

From an initial view, one can notice some striking visual similarities between *Santa Maria Della Neve* and *The Remaining Mountain*. The composition of the two drawings consists of a broad view of a mountain region with bodies of water from an elevated angle. Although landscape scenery is a common theme in ancient Chinese art, it was never an independent subject in Western art because the landscape was only a subject of background at that time. Therefore, even a resemblance in general appearance is rarely seen in other art pieces in Western art history. Beyond the visual representation, the creation of two drawings is similar in terms of artistic choices. Both drawings are products of the artists' own initiative rather than commissioned pieces, which is indicated by the artists' personal information on each art piece. The timestamp and signature on Leonardo's painting show that it was completed on 5 August 1473, when he was ending his apprenticeship with Verrocchio. (The inscriptions are in the upper left corner, written backward by Leonardo from right to left: "Dì di s[an]ta Maria Della neve / adj 5 daghossto 1473").⁵ Therefore, he may have made this drawing for his own reminiscence of a significant life experience. Gongwang, on the other hand, made the drawing of Fuchun Mountains as a gift to a fellow Taoist

5 "Study of Leonardo's First Landscape Finds he Had Second Thoughts, Added Later Details," *Japan Times*, <https://www.japantimes.co.jp/culture/2019/01/18/arts/study-leonardos-first-landscape-finds-second-thoughts-added-later-details/#XTU2J1wzbic>

named Master Wuyong (无用师). Gongwang added a short comment about the process of drawing and placed a stamp with his name on the scroll.⁶

Moreover, the two drawings have notable differences in size, format, and medium that can be compared and studied. Leonardo's drawing is small in scale, with a height of 19.0 cm (7.48") and a width of 28.5 cm (11.22").⁷ *Dwelling in the Fuchun Mountains* was once a long horizontal scroll with a height of 31.8cm. The lengths of the two separated scrolls vary greatly; *The Remaining Mountain* is 51.4 centimeters (a little over 20 inches), and *The Master Wuyong Scroll* is 636.9 centimeters (nearly 21 feet).⁸ Leonardo's drawing is an independent rectangle with a broad but fixed view of the Arno Valley. The rectangular frame shows Leonardo's strong implementation of Renaissance artist Leon Battista Alberti's "window" theory of painting. In Alberti's book *On Painting*, he summarized effective painting techniques for artists and explained his own painting methods. He wrote that the artist should create a "window" to compose a painting: "I inscribe a quadrangle of right angles, as large as I wish, which is considered to be an open window through which I see what I want to paint."⁹ The window frame in *Santa Maria Della Neve* is set up by Leonardo's vision. However, a long scroll, like *Dwelling in The Fuchun Mountains*, is not intended to be captured by a fixed range of vision. One should view a scroll by unrolling with one hand and re-rolling with the other to engage in a visual journey that unfolds with the dynamic movement of different sections of a panorama. In addition to size and format, the two artists exploited different media that were available to them in their historical and geographical context. Leonardo used pen and ink, which give his drawing tighter and more restrained lines. In contrast, Gongwang used traditional Chinese pen brushes, which have a softer quality and are harder to control. Pens are effective in developing greater details, while brushes allow the water to bleed and create a transparent effect.

6 Huang Gongwang, *Dwelling in the Fuchun Mountains*, Preface

7 "Landscape drawing for Santa Maria Della Neve on 5th August 1473," Web Gallery of Art, https://www.wga.hu/html_m/l/leonardo/11nature/01landsc.html.

8 "Landscape reunited: Huang Gongwang and Dwelling in the Fuchun Mountains," Tai Pei National Palace Museum, https://www.npm.gov.tw/exh100/fuchun/en_02.html.

9 Leon Battista Alberti. *On Painting* [First appeared 1435–36], Trans. John R. Spencer (New Haven: Yale University Press, 1970), 56.

Visual Evidence and Documentary on Similarities

Santa Maria Della Neve and *Dwelling in the Fuchun Mountains* depict similar elements of nature: mountains partly covered in trees, water near the mountainside, signs of human dwelling but an absence of people or activity. In particular, *The Remaining Mountain* has proportions and layout more like Leonardo's drawing. The composition of both pieces is well balanced with two subjects occupying each half of the picture: the right half has a lofty mountain, and the left half consists of plains and water viewed from a distance.

After closer observation, one might discover that both artists portrayed the scenes not from a single viewpoint, but rather from multiple perspectives. In the Western world, perspective is a fundamental paradigm of skilled, accurate drawing. Perspective is a highly utilized tool for artists to achieve an illusionary 3D effect with depth and height on a two-dimensional surface by converging the lines of recession at one (or more) point(s) on the picture plane. The meeting point of the parallel lines receding into space becomes projected at a finite point known as the vanishing point. Unlike Western drawing, Chinese drawing usually does not frame images through a single view but depicts the process of vision traveling across space and viewing the scenes from consecutive perspectives. This technique is known as the "scattered perspective". Moreover, the mechanism of a scroll, unlike the framed representation of Western paintings, reveals the landscape in sections, allowing a dynamic appreciation of the changes in its scenery, offering the viewer the opportunity to wander "inside" the painting at their own pace.

Unlike other works that strictly follow a mathematical perspective to depict proportions accurately, Leonardo's drawing of *Santa Maria Della Neve* does not rely on such precision. Here, mere visual inspection of the lines of the fields in the upper left corner of this sketch show there are many perspectives. The areas in the far distance seem to have a vanishing point in the far left, while the fields closer to the viewer seem to have one angled slightly to the left. As for the Montelupo Castle on the left cliff, its vanishing lines meet diagonally to the right, creating a third vanishing point. On the right portion, if Leonardo had strictly followed the scientific perspective, the trees in the drawing would also not have been in profile view. Based on common sense, if we were looking at them from above, we should see the top of the canopy; if we were to look at them from below, we would see the tall tree trunks extending into the sky. However, Leonardo's depiction of trees seems as though one is looking at them from ground level, seeing branches and leaves from the same angle as the trunk. Though Leonardo noted in his notebook that "the divisions of Perspective are three, as used in drawing; of

these, the first includes the diminution in size of opaque objects; the second, of the diminution and loss of outline in such opaque objects; the third, of the diminution and loss of color at long distances,"¹⁰ he did not apply the first rule of perspective. The trees in the bottom of the drawing, very near to where the viewer is standing, are almost the same size as the trees on higher elevations or at further distances.

Huang Gongwang was not trained to use perspective like a typical Western artist. Not only was mathematical perspective not established in ancient Chinese tradition; it is impossible to render continuous scenery through a single viewpoint. The format of the handscroll naturally combines multiple perspectives in the same drawing, embracing the landscape's breadth and depth along the river and mountains as an ongoing progress through space. Viewers cannot spot one-point perspective on detailed objects by converging vanishing lines in *The Remaining Mountain*. Therefore, the drawing is more visually consistent. Huang Gongwang drew the trees in a similar manner to Leonardo's. From the foot, along the ridge of the hill and to the top of the mountain, all the trees are in a consistent profile view. In the lower-left corner where the ground is a flat plain, the trees are not receding properly into the distance. The architectural structures at different heights are all in the same proportion and shape. The village on the left and the one in the middle of the painting are depicted in parallel lines instead of lines that converge to a vanishing point. In ancient China, it was common for artists to apply various perspectives to create large scale pieces that show the entirety of a traveler's view. According to Kwo-Da-Wei, "The Chinese concept of perspective, unlike the scientific view of the West, is an idealistic or surrealistic approach, so that one can depict more than can be seen with the naked eye."¹¹ A more philosophical way of explaining the perspective in Chinese painting can be traced to the influence of Taoism and the Yi Jing. Regardless of the subject's position, the relationship of distance is constant and objective. Painting in accordance with the mathematical perspective of the West creates distortion and human interference with the natural state of the objects. As advocated in the Yi Jing, the reality of the image should be filtered by the human eye to present its ontological state.¹²

10 Leonardo Da Vinci, *Notebooks of Leonardo Da Vinci*, ed. Jean Richter (New York: Dover Publications, 1972), 17.

11 Kwo Da-Wei, 1990, *Chinese Brushwork in Calligraphy and Painting* (New York: Dover Publications, 1991), 70.

12 Avril Accolla & Jixiang Jiang, "Creating an Inclusive and Participatory Way-finding Canvas for All," *Theoretical Issues in Ergonomics Science* 20, no. 2 (2019): 166-177, DOI: 10.1080/1463922X.2018.1522557

Another similarity between Leonardo's and Gongwang's works is their representation of depth in monochromic drawings. Instead of using vibrant paint to present nature, the drawings are done with minimal colors in different shades of dark ink to represent depth. In Leonardo's *Treatise on Painting*, he mentioned the color variation based on the proportion of distance: "The same colour being placed at various distances and equal elevation, the effect of its colouring will be according to the proportion of the distance which there is from each of these colours to the eye."¹³ Though a drawing like the *Santa Maria Della Neve* does not have the variety and vibrancy of colors in nature, a thorough visual inspection allows one to see Leonardo utilizing two different colors of ink to achieve the same effect as a painting. Dark black ink is used to emphasize the objects closer to the viewer, such as the trees and jagged edges of mountains in the front. The small area of woods in the bottom of the drawing is highlighted the most by the black ink. The twining branches are densely compacted, perhaps indicating the exuberance of plants in the valley, under the shade of the mountain. Thick black lines mark the contour of the cliff on the right side. Light strokes of messy lines decorate the barren cliff with flourishing plants on top. On the upper left, where the view draws further in depth into the paper, Leonardo applied brownish ink to make the distant mountains and the fields hazier and softer. He let the tonal effects of his pen lines recede gently as they reach the beyond, creating a smooth transition and overall harmonic scene.

In *The Remaining Mountain*, Gongwang applied darker ink when painting the robust mountain on the right side. Lush vegetation and rock forms are on the right hand, closer to the viewer. For the faraway mountains on the left, Gongwang deliberately avoided adding plant coverings or rock textures. This simplification of the distant mountains is in accordance with Leonardo's note about "The divisions of Perspective: the second, of the diminution and loss of outline in such opaque objects".¹⁴ Furthermore, Gongwang filled these distanced, plane mountains with lighter and fainter ink, which authentically depicts the misty effects of highland air. A few of the mountains only have a greyish hue but no distinct outline separating their forms from the blank spaces of the scroll. This approach Gongwang used to create an illusion of depth is called "atmospheric perspective." The concept of atmospheric perspective in Western art reflects of the theory of "three distances" in Chinese landscape paintings. Guo Xi 郭熙 (d. 1090), one of the most celebrated

13 Leonardo Da Vinci, *A Treatise on Painting*, trans. John Francis Rigaud (London: George Bell & Sons, 1906), 118.

14 Leonardo Da Vinci, *Notebooks of Leonardo Da Vinci*, 17.

landscape painters of the Song dynasty, outlined the theory of the San yuan 三远 (three distances [in the height, the depth, the breadth]), which set the basic principles for creating extensive distance and spaces in landscape paintings.¹⁵ In both artworks, the breadth and depth are the most pronounced features. The two images emphasized “breadth” through horizontal expansion with portions of mountains undepicted outside the drawing. The upper left section in the two pieces presents the vastness of mountains extending afar, perfectly demonstrating the “depth.”

Visual Evidence and Documentary Differences

The level of formality is one of the prominent disparities between *Santa Maria Della Neve* and *The Remaining Mountain*. Leonardo drew the scenery on a small sketch paper with only half the size of *The Remaining Mountain*. Presumably, this was because paper was expensive at that time and artists would not want to waste paper when practicing drawings. Unlike Leonardo's other finished works that were painted directly onto canvas or walls, *Santa Maria Della Neve* has Leonardo's signature and signed date, which shows the importance of this drawing to Leonardo. After completing this drawing, within months Leonardo ended his seven-year apprenticeship and started on his own. The drawing depicts a young artist's casual expression of a familiar scene from his childhood. Though Leonardo made the landscape of *Santa Maria Della Neve* for his leisure and self-expression, drawings in the Renaissance were mostly considered practice for an artist to prepare for their commissioned work to please the patrons. By comparison, *Dwelling in the Fuchun Mountains* is a more formal artwork that Huang Gongwang dedicated to a revered friend. According to Gongwang's own inscription on the handscroll, he spent seven years living in the Fuchun Mountains and took three to four years to finish the large-scale drawing. Rather than consciously constructing the drawing, Huang Gongwang worked on it on and off when the mood struck him.

Also, the Arno Valley is a relatively small area compared to the Fuchun region, which consists of hundreds of mountains. The foreground in Leonardo's drawing shows the solid terrain that the artist is standing on, suggesting that he is at the scene while working on his drawing. However, *The Remaining Mountain* does not show the ground that the artist is on. It offers an aerial view, as if the mountains the artist is looking down on the mountains from an airplane, indicating Huang Gongwang pulled this work from his mind.

15 Lin Quan & Gao Zhi. *Painting Collections of GuoXi* (Jinan City: Shandong, 2010).

Intriguingly, studies led by art historian Dr. Cecilia Frosinini show that Leonardo completed this work with two phases. The first phase was the landscape sketch done when the landscape view was available; the other phase is when he added more details to his original sketch. With extensive examination, experts conclude that Leonardo utilized different tools and materials when producing his painting: He used a lead stylus to outline, then elaborated the sketch using ink. The horizon line and mountain contour were meticulously superimposed, while the vegetation, water, and other rocks are freehand. Though many claim that this landscape is more of a “photograph” of Leonardo’s native Tuscany, evidence suggests that imaginative aspects also played a role in this artwork.¹⁶

The use of different drawing media is also a major difference between the two artworks. Both Leonardo and Huang Gongwang are masters at delineating the rocks, rivers, and various nature scenery in ink, yet Leonardo implemented a pen, and Huang Gongwang used a brush. The qualities of the two media lead to different effects on the artwork. The strokes of a pen are more compulsive and precise, and more suitable for making drawings on a small-sized paper. Leonardo managed to use varying textures of pen lines to create delicate details. He used short, horizontal strokes to suggest tree branches and leaves; thicker lines follow the contours of the solid landform. The small objects in the landscape are elaborately presented: the fortified castle partially hidden behind the mountain and the floating boats in dark shapes. The architectural structures drawn by the pen are more specific and realistic than those painted by brush. In Huang Gongwang’s drawing, the houses only have a general outline of the roofs and walls. While Leonardo applied slight variations in ink color (dark brown and black) to show the different levels of intensity, Huang Gongwang created various shades of black by controlling the amount of water in the brush to highlight or tune down the vegetation and rock forms.

In *Santa Maria Della Neve*, water is a subject of great emphasis. In Leonardo’s notebook, he described water as “the vehicle of nature” (*vetturale di natura*), water to nature is what blood is to our bodies.¹⁷ On the right-side

16 "The Diagnostic Campaign of the Opificiodelle Pierre Dure on the First Landscape by Leonardo."

17 "L'acqua Come Microscopio Della Natura. Il Codice Leicester di Leonardo da Vinci. Nota Introduttiva," Le Gallerie Deglie Uffizi, <https://www.uffizi.it/magazine/Nota-introduttiva-alla-mostra-Codice-Leicester>.

cliff, compacted straight lines present the waterfall rushing down from the heights, forming a swift swirl in the valley. The lines are curved and slightly wavy; some are passing through pebbles and sediments on the riverbeds. As the flow converges to the large lake in the distance, the strokes become sparser and straighter, indicating a less dynamic surface. The pen ink allows Leonardo to accurately imitate the flow of water, adding movement to the picture. Differently from Leonardo, Huang Gongwang drew bodies of still water. Surrounded by the undulating hills, the mirror-like lake contrasts with the mountain areas filled with ink lines, offering a sense of tranquility. Gongwang made his wash diluted with water and painted a little color on the water surface. The ink of the hills bleeds slightly into the lake, blurring the sharp edges as if one can see the shallow ground in clear waters.

Another element in Leonardo's drawing that is not observed in *The Remaining Mountain* is the presentation of light and shadow. In Leonardo's *Treatise on Painting*, he wrote: "Shadows appear to me to be of supreme importance in perspective, because, without them, opaque and solid bodies will be ill-defined."¹⁸ In this landscape drawing, the viewers can quickly identify that the light source is coming from the left side: the cliff where the castle perches has shadows on the right part of the rocks. With multiple lines of hatching, he built up a faint shadow on the distant hills. On the rock beneath his feet, Leonardo used black ink to make the shaded areas to stick out. On the right, the cliff wall that directly faces the sunlight is left blank, while the region facing the artist is shaded with soft pen lines.

Unlike Leonardo, traditional Chinese artists use lines to delineate structures instead of light effects. This is called Gufa method (bone method), which is derived from calligraphy¹⁹. Calligraphy was a fundamental part of art training because calligraphy could provide comprehensive practice for young artists to develop control over the subtlety of soft brush tips in various situations. After a well-rounded calligraphy training, artists would be confident in wielding the brush to draw images. When drawing, artists first outline the basic composition with light ink, then apply texture strokes, also known as "Cunfa, 皴法". Using texture strokes to outline the shapes of rock and mountain structures is an essential feature in Chinese landscape painting. Gongwang referred to several textural strokes developed by famous artists from the past. For example, Gongwang used "Pima Cun, 披麻皴"

18 Leonardo Da Vinci, *The Notebooks of Leonardo Da Vinci*, 111.

19 Xie He. *The Six Principles of Chinese Painting* (Beijing: Zhonghua Book Company, 1985).

textural strokes attributed to artists Dong Yuan and Juran in the 10th century. “Pima Cun” stands for “Hemp-fiber” strokes, which are the layers of long and thin strokes from the top to the bottom of the mountain. Also, the term “Fantou Cun, 矾头皴” is used the black boulder dotted by dark ink. It is used to represent small angular rock forms.²⁰

The Uniqueness of Leonardo’s Landscape Painting

Although Western paintings from the earliest ancient and classical periods included natural scenic elements, landscape as an independent genre did not emerge in the Western tradition until the Renaissance in the 16th century. The main theme in Western art is portraiture. Before Leonardo, a drawing of a landscape without human figures and symbolism would have been unimaginable. In contrast, landscape and nature is not only a popular subject in Chinese painting, but also at the top of the hierarchy of traditional Chinese painting styles. In the Western world, portraits of biblical figures expressing humankind’s reverence for heaven and religion are the most significant type of art. By contrast, Chinese artists associate nature with the sublime. This belief originates from the philosophy of Taoism, which emphasizes harmony between humans and nature, which is created by the heavenly world. *Santa Maria Della Neve* is not only Leonardo’s first documented artwork, but also the first drawing that has a landscape as the main subject, which makes its similarities to *The Remaining Mountain* more easily visible to viewers. The authenticity and realism of Leonardo’s work are conspicuous Western characteristic. In Christian

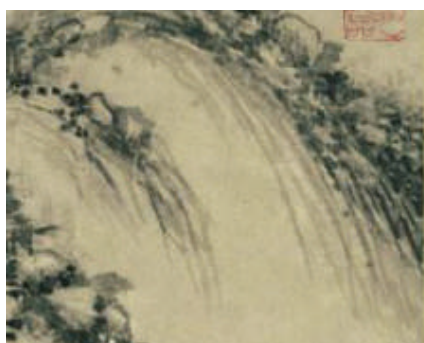


Figure 3.
Pima Cun



Figure 4.
Fantou Cun

20 Wen C. Fong, Chin-Sung Chang, and Maxwell K. Hearn, *Landscapes Clear and Radiant: The Art of Wang Hui (1632-1717)*, ed. Maxwell K. Hearn (New Haven: Yale University Press, 2008).

thought, it was believed that God is present in the natural environment.²¹ As a result, Leonardo strives for realistic expression in his passion for nature and landscape as his version of a contribution to God.

Reflections on the Similarities and Differences

The Chinese artists are in awe of nature for its eternity. The mountains are places to seek sanctuary from the secular world. Leonardo regards nature similarly to the Chinese. He believes “Human subtlety will never devise an invention more beautiful, more simple or more direct than does nature because in her inventions nothing is lacking, and nothing is superfluous.”²² By noting the perfection of nature’s invention, Leonardo implied the significance of studying nature by stating that nature itself is the paradigm of perfect art. Leonardo’s respect for nature propels him to do more work to explore to the natural surroundings, while other artists pay little attention to nature. Leonardo recorded in his notebook his disapproval of another renowned Renaissance artist Sandro Botticelli’s claim that drawing nature is useless and a waste of time.²³

Leonardo’s notebooks recorded his detailed analysis of trees and plants, animals, and the atmosphere. He studied nature like a scientist, observing the changes of leaves and flowers in different seasons, the sunrise, and the sunset. Leonardo carefully observed nature with eyes to develop great works of art, very much akin to Chinese art philosophy. Leonardo once said that “the eye, the window of the soul, is the chief means whereby the understanding can most fully and abundantly appreciate the infinite works of Nature”²⁴ An art critic in China called Shitao noted similar ideas: “Observing all kinds of mountains forms sketches.”²⁵ To clarify, Shitao means that observing nature is an effective method to prepare for artwork, just like making practice sketches.

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- 21 Neil MacGregor, "God is in the Details: Christ's Portrayal in Art is Crucial to How We All See Good and Evil," *The Independent*, February 25, 2000, Arts.
- 22 Leonardo Da Vinci, *The Notebooks of Leonardo Da Vinci*, ed. Jean Richter (New York: Dover Publications, 1972), 837.
- 23 Leonardo Da Vinci, *Leonardo Da Vinci Notebook*, Trans. Zhou Li (Jiangsu: Phoenix Publications, 2010), 56.
- 24 Leonardo Da Vinci, *The Notebooks of Leonardo Da Vinci*, 653.
- 25 Shi Tao, *Shi Tao Hua Yu Lu*, trans. Yu Jianhua (Jiangsu: Phoenix Publication, 2007).

In contrast to Leonardo's pursuit of resemblance to reality, Chinese artists valued personal perception and an understanding of nature. They believed that a noble artwork is more an image of the mind than a realistic portrayal of scenery. A good example that explains the difference between Leonardo's and Gongwang's observation process is the relation between man-made structures and natural scenery in their drawings. It is worth exploring why the artists inserted structures that show signs of human dwelling in a landscape but not humans. For Leonardo, it could be straightforward; he might have included the Montelupo Castle because it was on the site while he was drawing. It is possible that there were no people in the Valley when Leonardo was observing the landscape, or that he might have made a conscious decision not to draw humans. Given the scale of vastness and distance, one can see from the landscape that the proportion of humans would be tiny. Moreover, the paper size is too small for Leonardo to elaborate on human figures. As for *The Remaining Mountain*, Huang Gongwang included the houses to convey a symbolic meaning. It is very likely that no houses or humans can be seen from the viewpoint in the scroll. The houses concealed in the mountains are meant to reveal a yearning for a life of seclusion. It is the belief of Taoism that escaping the secular world and settling in the mountains allows one to reach a purely spiritual realm. Huang Gongwang himself was a hermit who followed Taoism and he was giving this scroll to a Taoist master, so he inserted the suggestions of seclusion into his landscape.

Leonardo and Gongwang also observe nature differently due to their personal and cultural backgrounds. Leonardo decided to be a professional artist who would live by producing paintings for a living. In Giorgio Vasari's *Lives of the Most Eminent Painters Sculptors and Architects*, his description of Leonardo Da Vinci says, "[. . .]and since he wished that his profession should be painting, he studied much in drawing after nature[. . .]"²⁶ Besides having an inborn talent and receiving systematic training under an esteemed mentor, Leonardo himself put much effort into learning the surroundings to achieve the visual resemblance of his art to the real world. He did extensive research on nature's timely variations and analysis of drawing techniques, such as methods of depicting shadows. Huang Gongwang did not start his art career until his twilight years. He belonged to the social class of literati, an educated elite group that composed calligraphy, art, and poetry. Huang Gongwang lived in the Yuan dynasty; a dynasty founded by the minor ethnic group Mongolians. However, most of the literati like Gongwang belong

26 Giorgio Vasari, *The Lives of the Painters, Sculptors and Architects, Volume Two*, ed. William Gaunt, trans. A. B. Hinds (New York: Dutton), 158.

to the Han ethnicity. They regarded Mongolians as intruders and refused to serve the emperor. They lived a reclusive life and sought for self-cultivation in drawings and calligraphy. Gongwang himself is one of the literati who pursued a carefree life in nature. Not an artist by profession, he did not train to draw systematically with techniques. Gongwang lived and traveled in the Fuchun mountains and gradually develop his own perception and sentiments towards this place. After years of observation, he rendered his scroll in freehand based on his experience.

Though both artists respect nature and regard nature as a supreme beauty that should be studied and presented in art, Leonardo's and Gongwang's different approaches to nature result in the distinct styles of their finished work. Leonardo was more like an enthusiastic observer and scientist eager to understand everything to enhance his artistic skill. Leonardo's attention to detail and the intellectual process proved his devotion to his professional career. As for Gongwang, the intended audience of his artwork was never the general public but his friends. Drawing was a part of his lifestyle and an expression of his inner spirit.

Conclusion

With excellent artistic skills and attachment to nature, Leonardo and Gongwang composed landscape drawings that captured beautiful corners of our earth. By comparing the two pieces, viewers can gaze at the similarities between the mountains in Florence and Hangzhou while also appreciating the different expressions based on the artists' cultural and personal backgrounds. The drawings give viewers an immersive experience of the fascinating natural scenery that once inspired two great artists a few hundred years ago. The numerous similarities and differences between the two works can be studied and compared thoroughly. From a general glimpse of just the subject, the layout, the composition, to a formal art analysis level, there are striking similarities between the two artists from different countries and historical periods. Leonardo and Gongwang are both obsessed with the natural world and are willing to spend time studying nature through their own methods. They are genuinely passionate artists who produce art according to their own initiative and interests. Both *Santa Maria Della Neve* and *The Remaining Mountain* emphasize the expression of the artists' temperaments.

It is also clear that Leonardo's and Gongwang's background differences lead to the different visual representations of the two artworks. The use of different paper material leads to the differences in the size of the artwork and drawing implements. Furthermore, the level of formality between the two works is determined by the artists' personal decisions and the purpose of the

drawing. Leonardo drew *Santa Maria Della Neve* to preserve the scenery of his beloved hometown for himself, but the drawing is not part of the preparation for a commissioned piece. Gongwang spent a longer time preparing for a scroll for his friend and instilled his Taoism philosophy in the work. Leonardo preferred to use hatchings to present 3D effects with shadows and lights. In contrast, Gongwang utilizes various outlining methods and textual strokes to vividly show an object's form and material.

Based on the level of completeness, *Dwelling in the Fuchun Mountains* and *The Remaining Mountains* better known and more studied by art historians than *Santa Maria Della Neve*. Gongwang's landscape is recognized as the mastery of an established art genre. In this case, Leonardo's landscape should be acknowledged as an extraordinary innovation in the choice of subject by a Western artist. Leonardo's attempt to dedicate a drawing solely to portraying a landscape is attributed to his fervent passion for detailed inspections of natural scenes that align with the Chinese philosophy of appreciating nature. The pursuit of rendering a holistic landscape combining broader scenes propels Leonardo to cease adhering to the rule of mathematic perspective and emphasize composing diverse natural elements. The Renaissance legend's creativity and artistic skills that successfully resulted in the invention of landscape, similar to a Chinese masterpiece, makes an exciting art history discovery. The resemblance in various aspects of *Santa Maria Della Neve* and *The Remaining Mountains* demonstrates a universal affection that humans have towards nature, which, in a broader perspective, allows art historians to investigate further whether Western and Chinese landscape traditions are completely different.



The Invisible Culture of Pain and the Opioid Crisis

Sumin Yoon

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Abstract

This research paper examines how the motivations for opioid abuse are shaped by analyzing the modern culture of pain behind the opioid epidemic. Even though the biological mechanisms of opioid overdose and dependence are widely researched, our understanding of why Americans turn towards opioids in the first place is rarely discussed. The difficulty in collecting this information lies in gathering and analyzing significant amounts of qualitative data that may be confounded with multiple variables. However, if we begin to understand the motivations for opioid abuse and the cultural and social factors that shape it, we will better understand those who are afflicted by opioid abuse and provide better treatment and prevention strategies. This research will mainly rely on the current literature on the opioid epidemic, pain, stress, STS, along with information from interviews. I will explore how the first two waves of the opioid epidemic were driven by the medicalization of addiction, and how this view cannot apply to the current wave of the synthetic opioid epidemic; I will further investigate the role of social pain and technology to argue that modern technoculture makes individuals more vulnerable to opioid abuse by promoting social pain and shaping how users cope with pain. I hope that the results from this study will allow the general public to better understand the current opioid crisis in the context of their modern culture.

1. Introduction

The current opioid epidemic killed more than 70,000 people, contributing to the ongoing drug overdose death toll that is higher than the number of deaths caused by HIV, car crashes, or gun violence.¹ Yet, the opioid crisis is rarely an issue that Americans talk about. When I drive to my school, I see countless billboards warning about the dangers of cancer and drunk driving; the opioid epidemic, on the other hand, was previously invisible in my daily life until I picked up Beth Macy's *Dopesick* out of mere curiosity.

However, the opioid crisis is not new. In 1853, the development of the hypodermic needle allowed for direct injection of morphine to become the standard practice for treating the pain of Civil War soldiers, causing morphine addiction to soar.² Opioids refer to any chemical derivatives originating from the poppy plant; throughout history, opium changed into morphine, and morphine into heroin, OxyContin, and fentanyl.³ Some used these substances to treat morphine addiction and pain, while others used them for recreational purposes.

This research examines why an increasing number of Americans fall victim to opioid abuse through the analysis of current research on the opioid crisis and pain, along with interviews. I explore the topic of social pain, a form of stress that results from loss of social relationships, through the lens of STS and how our perception of this pain has changed with the rapid medicalization of opioid addiction and the growth of technology in our personal lives.⁴ Although the biological mechanisms of opioid overdose and dependence are thoroughly researched, our understanding of why Americans turn towards opioids in the first place is rarely discussed. Therefore, there is a need to better understand the invisible cultural and social factors that lure users to opioids in hopes of improving treatment and prevention methods.

1 Katz, Josh, and Margot Sanger-katz. "The Numbers Are So Staggering,' Overdose Deaths Set a Record Last Year." *The New York Times*. The New York Times, November 29, 2018. <https://www.nytimes.com/interactive/2018/11/29/upshot/fentanyl-drug-overdose-deaths.html>

2 Macy, Beth. *Dopesick: Dealers, Doctors, and the Drug Company That Addicted America*. New York, NY: Back Bay Books, Little, Brown and Company, 2019.

3 Ibid.

4 Baum, Andrew, Carroll Lee, and Angela Dougall. "Social Stressors, Social Pain, and Health." *Neuropsychological and Health Implications of Loss and Exclusion*, 2011, 193–213.

2. Literature Review

2.1 History of the Opioid Epidemic

The first wave of the current opioid crisis began in 1995 with the shift towards pain as the “Fifth Vital Sign,” while the second wave occurred as users shifted from prescription opioids to street heroin in 2010.^{5,6,7} The transition of pain from a simple physiological sensation to an important marker of health was quickly followed by the development of new painkillers such as OxyContin. OxyContin eventually became the most common painkiller because of its self-proclaimed ability to treat chronic pain with less than 1% risk of addiction.⁸ Although the methodology behind this statistic was vague and unclear, physicians quickly adopted this notion of safe opioid painkillers.⁹ This transition in the perception of opioids from dangerous and addictive medication to a safe panacea of pain highlights people’s trust in scientific research to develop technologies that seem to promise the impossible, even though previous knowledge tells us otherwise.¹⁰

Many researchers blame this false belief of non-addictive opioid painkillers held by pharmaceutical companies and physicians as the prime cause of the opioid epidemic. Because the frequent prescription of highly addictive OxyContin eventually resulted in many patient-addicts, opioid policy researcher Andrew Kolodny argued for a greater focus on treating opioid

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- 5 Cicero, Theodore J., and Matthew S. Ellis. “The Prescription Opioid Epidemic: a Review of Qualitative Studies on the Progression from Initial Use to Abuse.” *Dialogues in Clinical Neuroscience*, September 2017. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5741109/>.
 - 6 Baker, David W. “The Joint Commission’s Pain Standards and the Prescription Opioid Epidemic.” *JAMA*. American Medical Association, March 21, 2017. <https://jamanetwork.com/journals/jama/article-abstract/2606790>.
 - 7 Dasgupta, Nabarun, Leo Beletsky, and Daniel Ciccarone. “Opioid Crisis: No Easy Fix to Its Social and Economic Determinants.” *American Journal of Public Health*. American Public Health Association, February 2018. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5846593/>.
 - 8 Kolodny, Andrew, David T. Courtwright, Catherine S. Hwang, Peter Kreiner, John Eadie, Thomas W. Clark, and G. Caleb Alexander. “The Prescription Opioid and Heroin Crisis: A Public Health Approach to an Epidemic of Addiction.” *Annual Reviews. Annual Review of Public Health*, January 12, 2015. https://www.annualreviews.org/doi/full/10.1146/annurev-publhealth-031914-122957?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub=pubmed.
 - 9 Baker, “The Joint Commission’s Pain Standards and the Prescription Opioid Epidemic”
 - 10 See Kolodny “The Prescription Opioid and Heroin Crisis: A Public Health Approach to an Epidemic of Addiction.”

addiction among prescription users rather than preventing illicit non-medical use. This shift in focus towards treating opioid addiction would prevent the transition from opioids to heroin that results from limiting opioid supply without treating addicts.¹¹

While researchers David Baker and Theodore Cicero credit the abundant supply of opioids from overprescription as the major driver of the epidemic, epidemiologist Nabarun Dasgupta argues that, at its core, the opioid crisis is driven by social and economic problems. Dasgupta agrees with Kolodny's claim that the second wave of the opioid crisis is a result of growing regulation of the opioid supply. As an effect, addicts who lost their source of opioids turned towards cheaper and more easily accessible heroin.¹² However, Dasgupta asserts that limited treatment for addicts is not the only factor that drove the second wave; he argues that the second wave is catalyzed by people's desire to "somaticize social disasters into physical pain," explaining that social factors such as income inequality and low socioeconomic status can manifest as physical pain.¹³ Analysis of recent studies shows that there is a shift in how researchers are viewing the opioid crisis—instead of simply attempting to limit the opioid supply, they are paying more attention to sociocultural contexts that attract people to illicit non-medical opioids such as heroin.

We are currently in the 3rd Wave of the Opioid Epidemic. Unlike the first two waves of the crisis, in which people were impacted by prescription painkillers and heroin, the third wave is characterized by the rise of synthetic opioids contaminating the illicit opioid market.¹⁴ It is important to note that more people have died from prescription opioids; however, the number of prescription overdose (OD) deaths has stabilized since 2016, while deaths from other synthetic opioids have exponentially increased.¹⁵

11 Ibid.

12 Dasgupta, Nabarun, Leo Beletsky, and Daniel Ciccarone. "Opioid Crisis: No Easy Fix to Its Social and Economic Determinants." *American Journal of Public Health*. American Public Health Association, February 2018. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5846593/>.

13 Ibid.

14 Frostenson, Sarah. "The Opioid Epidemic's Startling Age Divide." *Vox*. April 26, 2017. Accessed August 16, 2019. <https://www.vox.com/science-and-health/2017/4/26/15389644/opioid-heroin-epidemic-startling-age-divide>.

15 "Opioid Overdose." Centers for Disease Control and Prevention. December 19, 2018. Accessed August 16, 2019. <https://www.cdc.gov/drugoverdose/epidemic/index.html>.

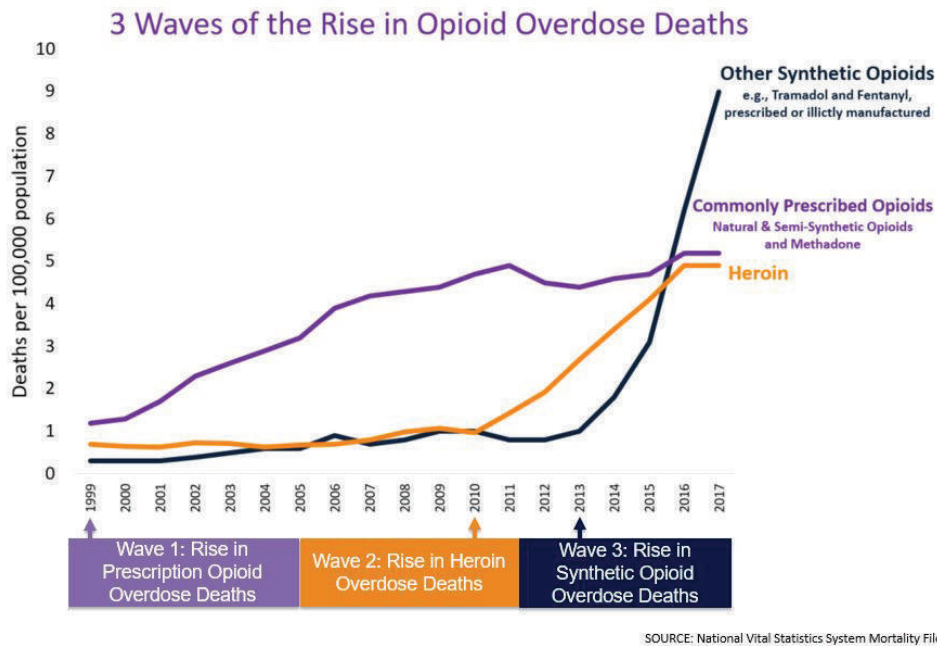


Figure 1.
Center for Disease Control, 2018¹⁶

This shift in focus from prescription opioids to novel synthetic opioids, such as fentanyl, is also impacting different groups. In contrast to the first two waves, where the majority of prescription overdose was concentrated on older Americans aged 50–60, fentanyl overdose mostly impacts young adults aged 25–34, who are also the largest victims of heroin overdoses.^{17,18} In fact, heroin OD deaths involving synthetic opioids have been rapidly rising, as shown in the graph below:

¹⁶ Ibid.

¹⁷ Spence, Merianne, Margaret Warner, and Brigham Bastian. “Drug Overdose Deaths Involving Fentanyl, 2011–2016.” *National Vital Statistics Reports* 68, no. 3 (March 21, 2019). https://www.cdc.gov/nchs/data/nvsr/nvsr68/nvsr68_03-508.pdf.

¹⁸ Frostenson, Sarah. “The Opioid Epidemic’s Startling Age Divide.”

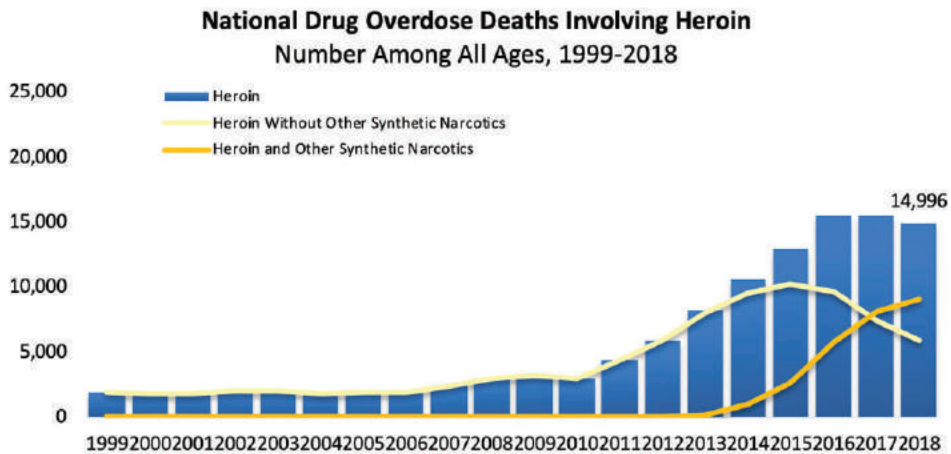


Figure 2.

National Institute on Drug Abuse, 2019.¹⁹

The emergence of fentanyl as the next deadly drug will not be the end of this opioid crisis. There are numerous other synthetic opioids, many of which were initially developed as painkillers but failed to be brought into the market.²⁰ Because they were not brought to the market and tested, it is unknown how these drugs will react with the human body.²¹ There are many potential reasons for fentanyl being used in the black market supply, but it is ultimately an experiment designed by drug dealers to utilize a vulnerable population to test and market more powerful drugs.

The current opioid crisis is no longer the story of getting injured, going to the doctor, and getting addicted to opioids due to overprescription. Instead, it is a story of young Americans who are increasingly turning to the illicit opioid market. We need to understand the invisible social and cultural forces that are pulling young adults into the fentanyl-contaminated, illicit opioids in the first place. This knowledge will allow us to prevent initial exposure to the contaminated opioid supply, which will in turn reduce the ever-high overdose mortality. We have entered a new wave of the crisis in which there is no guarantee that users will ever return safely from their next high.

¹⁹ National Institute on Drug Abuse. "Overdose Death Rates." NIDA. January 29, 2019. Accessed August 16, 2019. <https://www.drugabuse.gov/related-topics/trends-statistics/overdose-death-rates>.

²⁰ Lucyk, Scott N., and Lewis S. Nelson. "Novel Synthetic Opioids: An Opioid Epidemic Within an Opioid Epidemic." *Annals of Emergency Medicine* 69, no. 1 (January 2017): 91–93. <https://doi.org/https://doi.org/10.1016/j.annemergmed.2016.08.445>.

²¹ Ibid.

2.2: Motives for Opioid and Other Drug Abuse

Motives for prescription opioid abuse can be categorized into medical abuse and non-medical abuse. Medical abuse refers to the use of prescribed opioids “not intended by the prescriber”, while non-medical abuse is defined as “use of someone else’s prescription opioids.”²² This categorization of opioid abusers is probably necessary to distinguish the new rising group of non-medical abusers who no longer have access to prescriptions due to the increased regulation of medical opioids. However, even though both types of abusers ultimately misuse opioids, medical abusers are more likely to receive public sympathy than non-medical users, who are criminalized. This distinction between medical and non-medical abuse ultimately exemplifies the role of medicine in normalizing medical abusers who can access healthcare while stigmatizing non-medical abusers who cannot.

Researcher James Zancy aims to investigate the different motives behind non-medical opioid use among college students by using an online survey. Students are allowed to select one or more motives for their non-medical prescription opioid misuse:

“Because it relieves pain”

“Because it gives me a high”

“Because it helps decrease anxiety”

“Because it’s safer than street drugs”

“Because it counteracts the effects of other drugs”

“Because I am addicted”²³

Respondents were also assessed on other “problematic drug use”, such as marijuana, cocaine, ecstasy, LSD, psychedelics other than LSD, heroin, crystal methamphetamine, inhalants, and binge drinking through Drug Abuse Screening Test (DAST-10).²⁴ Zancy discovered that the majority (63%) of non-medical users use prescription opioids to relieve pain and that 40% of non-medical users use it *only* to relieve pain. However, there is a striking

22 McCabe, Sean Esteban, Brady T West, and Carol J Boyd. “Motives for Medical Misuse of Prescription Opioids among Adolescents.” U.S. National Library of Medicine. *The Journal of Pain*, October 2013. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3792708/>.

23 Zancy, James P. “Non-medical Use of Prescription Opioids: Motive and Ubiquity Issues.” *The Journal of Pain*, June 2008. [https://www.jpain.org/article/S1526-5900\(08\)00348-9/fulltext](https://www.jpain.org/article/S1526-5900(08)00348-9/fulltext).

24 Ibid.

association between motive and drug abuse. For non-medical users whose motive is solely to relieve pain, “their likelihood of experiencing [three] or more drug-related problems” did not differ from medical abusers or non-users.²⁵ In contrast, non-medical users who reported other motives, or had other motives in addition to pain relief, were 15 times more likely to have three or more drug-related problems and increased likelihood of illicit substance use.²⁶

Zancy’s findings were corroborated by researcher Sean McCabe, who conducted a similar survey on 7th-12th graders. Similarly, McCabe concludes that non-medical users who use opioids for motives other than pain relief had higher rates of other substance abuse than non-medical users who use it only for pain relief. McCabe also notes that these motive-based abuse patterns applied to both medical and non-medical abusers.

Zancy and McCabe’s research ultimately shows that the motive behind drug abuse, whether the drugs are prescribed or not, results in different drug-seeking behaviors. This highlights the possibility that the second wave of the opioid crisis, which is characterized by increased heroin use, may be driven by motives other than pain relief. While the first wave of the opioid crisis was targeted towards treating physical pain, the role of opioids in today’s society seems to be multifaceted: they are used to treat physical pain *and* to relieve anxiety *and* to help people sleep *and* for them get high.²⁷ Are death tolls behind opioid abuse rising because more people are turning towards painkillers to solve other issues, or are people simply experiencing irregular amounts of these *other stressors* than they have in the past? Before we answer these questions, we need to dig deeper into different aspects of pain and individual motives.

Cicero investigates the motives behind prescription opioid abuse by reviewing qualitative interviews rather than relying on quantitative data like Zancy and McCabe. Cicero categorizes these motives for opioid abuse into “response to life stressors,” “self-medicating psychological issues” or “emotional pain.”:

“Something about that confidence . . . [I] believed that I did things better on opiates”

“You don’t get high anymore . . . You just get okay” “And if you don’t take it, you get really sick”

25 Ibid.

26 Ibid.

27 McCabe, “Motives for Medical Misuse of Prescription Opioids among Adolescents”

“A lot of us do them because we’re so unhappy in our relationships and with our lives”

“Not being comfortable in my own skin, being shy, being uncomfortable around other people . . .”²⁸

The quotes above show an emphasis on social and emotional pain rather than physical pain. For example, people take opioids to escape their shyness and low self-confidence in order to improve their sociability. Cicero’s survey of 25,000 drug addicts further supports his claim: the survey revealed that the main motive for drug abuse is not to simply “get high,” but to relieve depression and to feel like a “better, more popular person.”²⁹ Ultimately, these interviews suggest that the new power behind opioids is not only the chemical addictiveness, but also their ability to lift the burden of people’s deepest insecurities and their most unwanted emotions.

In conclusion, current research on motives of opioid abuse shows that there is more to it than simply relieving pain or getting high. Instead, people turn to opioids to be better versions of themselves and improve social abilities. Although these reasons are not directly associated with pain, the undertone of these situations can be associated with pain. This transition of opioids from a painkiller to a powerful alleviator of social insecurity and emotional discomfort indicates the current generation’s growing inability to cope with stress without the assistance of biomedicine.

2.3 Medicalization of Addiction and Pain

With the development of fMRI technology that pushed the belief that addiction can be best treated by understanding the brain, addiction gradually became medicalized as a disease of the brain.³⁰ Although understanding the neurobiology of addiction could result in targeted treatment, addiction has been medicalized to the point that social and environmental factors are neglected. In this section, we will examine how the medicalization of

28 Cicero, “The Prescription Opioid Epidemic: a Review of Qualitative Studies on the Progression from Initial Use to Abuse.”

29 Remerowski, Gaia. “Inside an Epidemic.” *Outlook Magazine*. Washington University School of Medicine in St. Louis, September 20, 2018. <https://outlook.wustl.edu/inside-an-epidemic/>.

30 Singh, Ajay. “Medicalizing Addiction.” *Freedom Magazine*. May 24, 2017. Accessed August 16, 2019. <https://www.freedommag.org/magazine/201704-addiction/medicalizing-addiction.html>.

addiction creates race-based victimization and reinforces people's reliance on biomedicine as a simple and quick cure for a complex problem.

The opioid epidemic is not the first drug epidemic in the United States. While the current opioid crisis disproportionately affects white users, many victims of the 1960s War on Drugs were black or Latino.³¹ There is a staggering difference in how black and Latino drug users were portrayed in contrast to white drug users. While the media often portrays white users as innocent victims of their surroundings, minority users were depicted as morally corrupt criminals.³² This sense of racial bias that drove the War on Drugs in the 1960s still manifests itself today in addiction treatment centers. For instance, black and Latino heroin users often visit methadone centers to seek addiction treatment; however, these facilities contain a high level of surveillance that ultimately creates a "quasi-punitive ethos" and an atmosphere of mutual distrust between patients and workers.³³ On the other hand, buprenorphine centers, which are primarily promoted to white, middle class addicts, are less stigmatized and encourage autonomy rather than surveillance.³⁴ This culture of distrust, punishment, and surveillance may discourage abusers from returning to treatment and exemplifies the role of racial bias in providing one particular group with a new opportunity for recovery while implicitly punishing and threatening abusers of color.

These segregated treatment centers highlight the fact that there is a difference in how Americans view white versus non-white drug users: non-white users are perceived as deserving punishment because they "choose" to do drugs while white users are viewed as victims of their surroundings (e.g. pharmaceutical companies and misinformed physicians).³⁵ The fact that there was a shift in perspective in how people view drug addicts as the demographics of users changed highlights the role of racial bias in tainting the view of addiction. The medicalization of addiction simply reinforced this racial bias in how people see non-white drug users by only applying the "disease of the brain" definition to white users while the rest were continued to be seen as moral failures. This may explain the disparity in predominantly white versus non-white addiction centers noted above.

31 Mendoza, Sonia. "Re-Racialization of Addiction and the Redistribution of Blame in the White Opioid Epidemic." *Medical Anthropology Quarterly* 33, no. 2 (June 2019): 242–62. <https://doi.org/https://doi.org/10.1111/maq.12449>.

32 Ibid.

33 Ibid.

34 Ibid.

35 Ibid.

The medicalization of addiction not only strengthens race-based victimization, but it also exemplifies people's desire to quickly solve complex problems with biomedicine. For example, the selective serotonin reuptake inhibitor drug best known under the brand name Prozac was guaranteed to treat depression by restoring the chemical balance in the brain.³⁶ Prozac was deeply rooted in the chemical imbalance theory that asserted depression is solely caused by a chemical imbalance in the brain, and that restoring this chemical balance would cure depression.³⁷ The adoption of this theory ultimately shifted the standards of treating depression from psychotherapy, which takes into account individual factors, to impersonal pharmacotherapy.³⁸ Although chemical imbalance may play a part in driving depression, it is not the only cause, because if the theory were to be true, Prozac could cure every case of depression. The harsh reality is that depression is caused by numerous other factors, such as individual history and environment, that cannot be simply fixed by a single pill. However, there is always an attraction towards new technologies that promise to cure the deepest of human problems "quickly, easily, and painlessly," even though they may simply be an illusion.³⁹

This view of medicalization is already infiltrating the way we treat opioid addiction. With the development of medication-assisted treatment (MAT) that uses "slow acting opioids" to manage cravings and withdrawal symptoms, there has been less emphasis on no-pill based programs.⁴⁰ This is partly because MAT is covered by insurance, while most "drug-free" programs are not.⁴¹ Although many studies show that MAT for treating opioid addiction is promising, increased focus on the biological mechanisms of addiction fails to answer why people become addicted in the first place and ignores the social environments that may foster drug-seeking behaviors. After all, we may be falling for the same story of Prozac and OxyContin. How wonderful would it be to not only treat, but to *cure* depression, pain, and addiction with the power of a single pill? This is not to say that MAT must be completely eradicated; rather, there needs to be a balance between MAT and personal treatment that aims to uncover the hidden social factors that drive addiction.

36 Goldhill, Olivia. "30 Years after Prozac Arrived, We Still Buy the Lie That Chemical Imbalances Cause Depression." *Quartz*. January 13, 2018. <https://qz.com/1162154/30-years-after-prozac-arrived-we-still-buy-the-lie-that-chemical-imbances-cause-depression/>.

37 Ibid.

38 Ibid.

39 Ibid.

40 Singh, Ajay. "Medicalizing Addiction."

41 Ibid.

If not, MAT treatment will be another familiar “pill-pushing” campaign like the one that drove the opioid crisis, and we *cannot* afford another one.⁴²

2.4 Pain and Stress

As previously discussed, one of the main motives for medical and non-medical use of opioids is pain relief. But what exactly is pain? In this section, we will explore the multiple definitions surrounding social pain and its relationship to the current opioid crisis.

Social Pain is defined as a distressing experience that results from the perception of social disconnection.⁴³ This sense of social disconnection often reflects social rejection, ostracism, or any other type of situation that negatively limits the individual’s social behavior.⁴¹ Researchers have discovered that social pain often shares a similar neural process with physical pain, both of which are associated with the dorsal anterior cingulate cortex.^{44,45,46,47} The similarity in the perception of social and physical pain indicates that social pain also serves as an evolutionary warning system.⁴⁸ Because humans are social creatures who depend on social networks for survival, social pain may act as a “warning sign” to encourage victims to avoid social exclusion.⁴⁹

However, instead of maximizing the individual desire to participate in social-enhancing activities, social pain may result in social anxiety, which further disconnects the individual from his or her social network due to a fear of social rejection.⁵⁰ Therefore, there is a subtle difference between social

42 Ibid.

43 Baum, Andrew, Carroll Lee, and Angela Dougall. “Social Stressors, Social Pain, and Health.” *Neuropsychological and Health Implications of Loss and Exclusion*, 2011, 193–213.

44 Ibid.

45 Baum, Andrew, Carroll Lee, and Angela Dougall. “Social Stressors, Social Pain, and Health.” *Neuropsychological and Health Implications of Loss and Exclusion*, 2011, 193–213.

46 Gunn, John F., III. “The Social Pain Model.” *Crisis: The Journal of Crisis Intervention* 38, no. 5 (2017): 281–86. Accessed August 16, 2019. doi:10.1027/0227–5910/a000510.

47 Fung, Klint, and Lynn E. Alden. “Once Hurt, Twice Shy: Social Pain Contributes to Social Anxiety.” *Emotion* 17, no. 2 (March 2017): 231–39. Accessed August 16, 2019. doi:10.1037/emo0000223.

48 Wu, Karen, Ph.D. “5 Reasons Why Social Pain Is Real.” *Psychology Today*. June 23, 2019. Accessed August 17, 2019. <https://www.psychologytoday.com/us/blog/the-modern-heart/201906/5-reasons-why-social-pain-is-real>.

49 Gunn, John F., III. “The Social Pain Model.” *Crisis: The Journal of Crisis Intervention* 38, no. 5 (2017): 281–86. Accessed August 16, 2019. doi:10.1027/0227–5910/a000510.

50 Ibid.

anxiety, which is an individual doubt of social ability, and social pain, which is an “unpleasant emotional state” resulting from social disconnection.⁵¹

While some define social pain as arising from social disconnection, Bourgois offers an alternative definition. His investigation of the life of Edge-water homeless heroin users revealed that the homeless are not only exposed to physical pain, but also non-physical pain. These types of non-physical pain include social ostracism, the anxiety of law enforcement, and fear of hunger.⁵² Bourgois ultimately argues that this non-physical pain drives homeless users to cheap heroin for relief. Therefore, social pain can also be defined as a response to life stressors, such as stigmatization, low socioeconomic status, racism, and limited access to necessities, such as shelter and food.

People cope with pain in two ways: they either avoid it or they approach it.⁵³ Avoiders believe that their pain is dangerous, so they minimize their pain as much as possible. This often causes disability and distress from living an irregular lifestyle of minimal physical work and social interactions.⁵⁴ In contrast, those who approach their pain learn to adapt and live with their pain, which fails to harm their quality of life.⁵⁵

However, the way individuals cope with pain is influenced by environmental and social factors.⁵⁶ Holtzman’s study shows the role of social support in how Rheumatoid Arthritis patients cope with their pain. Unlike the simple avoider (maladaptive) vs approacher (adaptive) coping mechanisms, Holtzman asserts that there are four types of coping mechanisms: cognitive reframing, stoic distance, emotional expression, and problem solving. Results show that patients were more likely to use these coping mechanisms when they had a positive perception of social support.⁵⁷ Although this positive social support is associated with both adaptive and maladaptive coping, patients with negative social support were only associated with maladaptive

51 Fung, Klint and Lynn E. Alden, “Once Hurt, Twice Shy: Social Pain Contributes to Social Anxiety.”

52 Ibid.

53 Bourgois, Philippe I., Jeff Schonberg, and Jeffrey Schonberg. *Righteous Dopefiend*. University of California Press, 2009.

54 Malpus, Zoey. “Coping Styles.” In *Pain: A Review Guide*, 353–55. Springer International Publishing, 2019.

55 Ibid.

56 Ibid.

57 Holtzman, Susan, Sarah Newth, and Anita Delongis. “The Role of Social Support in Coping with Daily Pain among Patients with Rheumatoid Arthritis.” *Journal of Health Psychology* 9, no. 5 (2004): 677–95. Accessed August 16, 2019. doi:10.1177/1359105304045381.

coping.⁵⁸ The study is still inconclusive if greater usage of these coping styles results in better pain outcomes.⁵⁹ However, this study shows that negative social support does correlate with maladaptive coping strategies that often cause individuals to avoid their pain or seek quick solutions instead of learning to live with it.⁶⁰

In the human body, physical and social pain seem to share similar pathways. Both types of pain signal to the body that something is wrong and compel individuals to either stop the discomfort or to cope with it. Therefore, the argument that opioid abuse is solely caused by physical pain relief is incomplete. Because social and physical pain share similar biological pathways, it can be argued that painkillers are effective in temporarily relieving social pain. The next section will examine why young Americans are increasingly turning towards opioids in the context of social pain, and how the role of technology is shaping the culture of disconnectedness and instant relief.

3. Data, Methods, and Interview Question Description

This section examines the different perspectives on the culture of pain, technology, and opioid abuse among the following individuals. The information was gathered through an interview in which respondents were asked to answer the five questions listed below.

Individuals Interviewed:

- Addiction Counselor
- Two High School Seniors

In this interview, “pain” could refer to physical, emotional, and social pain. The identity of the respondents will remain anonymous and an appropriate pseudonym will be used.

Questions Asked

1. What do you think is the major motive behind non-medical drug use of heroin, opioids, etc.? Why?
2. How has your perception or how you deal with pain changed throughout your life? If there is any change, what caused it?

58 Ibid.

59 Ibid.

60 Ibid.

3. Do you think technology helps you positively cope with pain? Why or why not? Examples of technology include pharmaceutical medication, social media, television, etc.
4. Do you think there is a social norm that pressures people to cope with pain or stress in a particular way? If so, please elaborate.
5. Do you think the younger generation feels more pain or stress than the older generations? How do you think the expression and perception of pain differs and why do you think that is?

The response to the interview suggests information that is both consistent and inconsistent with the literature. For instance, all three respondents believed that the major motive behind non-medical drug use is to either “escape reality” or “stretch . . . mental and physical capabilities.”^{61,62,63} One respondent also stated that environmental factors are also an important factor, which is consistent with the literature’s shift from pharmaceutical companies to social factors that influence drug use.

However, there is a diversion of opinions to the question of whether technology helps individuals cope positively with pain. The addiction counselor argued that technology helps non-medical users to “continue their bad habits” and “further isolate [them] from positive activities [and] people who support them.” On the other hand, the two high school seniors assert that technology helps them cope with pain by “providing a distraction.” Therefore, technology can help non-drug users cope positively with daily life stressors by providing entertainment, while also negatively impacting non-medical users by further restricting their social support, which can result in greater social pain.

Most interestingly, this interview provides evidence for an inconsistent reality in how people express pain. When asked if they feel that the younger generation feels more pain than the older generation, both high school seniors replied that “pain and stress” is more frequently talked today than in the past. They attribute this to the growing culture of acceptance in current society, which motivates the younger generation to take action, such as through social activism, to express pain and stress freely. Although the younger generation is more likely to express pain freely due to historical

61 Paul Morabid (high school senior), interviewed by Su Min Yoon at Dallas, August 22, 2019.

62 Jesse Chavez (high school senior), interviewed by Su Min Yoon at Dallas, August 20, 2019.

63 Laurie Wold (addiction counselor), interviewed by Su Min Yoon at Dallas, August 19, 2019.

factors, respondents believe that this idea of pain expression did not apply to social media. Instead, they believe social media pushes “people to be silent about the pain” and solely portrays an unrealistic image of never-ending happiness. This shows a discrepancy in how people act in reality versus online: even though the younger generation is more likely to express pain through activism, they are more likely to suppress their expression of pain in the virtual world.

4. STS Analysis and Findings

The growing reliance on opioids can also be explained in the context of STS, which focuses on the role of opioids as not only pills, but artificial technology aimed at enhancing human functions. Haraway’s cyborg technoculture, which describes the blend of technology with the human body, can be used to give a new perspective on the opioid crisis. The term cyborg applies to anyone whose bodies are physically melded with technology or viewed as a “high-performance machine” that can be enhanced and manipulated.⁶⁴ For instance, modern athletes exemplify a cyborg because of their heavy reliance on performance-enhancing drugs and protein powders, all of which are artificial technologies that elicit a particular outcome.⁶⁵ In the context of cyborg technoculture, opioids are similar to pacemakers and prosthetics that improve the function of the human body: prosthetics help people gain mobility while opioids help restore their sense of happiness. Therefore, opioid users are able to “construct [their] own identit[ies]” by independently controlling their emotions with a single pill.⁶⁶ Consequently, in the context of cyborg technoculture, opioid abuse may not necessarily be *abuse*, but an attempt to “escape the annoying bodily limitations” with technology and reach a more perfect version of ourselves.⁶⁷

The reason people increasingly turn towards these technologies reflects the current culture of hyper-efficiency. We want our internet to be faster and our lives to be more efficient. This desire is the primary motive for technological development. For example, social media allows users to connect with others in an instant, and we increasingly spend more time on screen because it is efficient. However, this virtual life is more stressful than it sounds. Social technology judges individual social behavior based on the number of “likes”

64 Kunzru, Hari. “You Are Cyborg.” *Wired*. December 15, 2017. Accessed August 22, 2019. <https://www.wired.com/1997/02/ffharaway/>.

65 Ibid.

66 Ibid.

67 Ibid.

a person receives, and pressures users to continuously express happiness. This unnatural behavior eventually detaches individuals from reality, which may explain why the driving force behind illicit drugs is to “live in the moment” rather than simply to exist in an online world.⁶⁸ The world may be more connected than ever before, but modern Americans are also the most socially disconnected generation, struggling to make their lives a bit more “saner, bearable, and magical.”⁶⁹ The growing use of illicit psychedelics and opioids reflects this growing need for social meaning rather than empty connections.

This culture of hyper-efficiency not only limits meaningful social interactions that humans need, but it also influences how we view our own internal struggles. Nearly 3 out of 4 college prescription abusers misuse Adderall to help with concentration and studying.⁷⁰ The fact that college students are turning towards prescription medications to boost their academic abilities highlights their desire to quickly fix their problems to keep up with the fast-paced world. The rise in technology has made daily problems easier to solve and reinforces the principle of minimal effort, or a “desire to seek the easiest way to achieve.”⁷¹ The growing reliance on this principle may be the driving force behind the rise in non-medical opioid use. People are sacrificing their social connections and replacing human interactions with technological ones for the sake of efficiency. This decrease in individual social network creates a sense of isolation, depression, anxiety, and other emotionally uncomfortable sensations of social pain. When users are faced with this pain, they are more likely to turn back to technology to cope with their stress instead of coping with other individuals, as shown in the previous interview. This lack of social support fosters maladaptive coping mechanisms that encourage users to seek quick solutions rather than reaching out to others for help, which explains why people are increasingly turning towards opioids to temporarily solve a multitude of problems, as noted in the literature review.

68 Kantrowitz, Lia, and Mike Power. “Our Depressing World Has Brought On a Psychedelic Renaissance.” *Vice*. December 04, 2018. Accessed August 22, 2019. https://www.vice.com/en_us/article/8xp8g4/the-psychedelic-resistance-v25n4.

69 Ibid.

70 Teter, Christian J., Sean Esteban McCabe, Kristy Lagrange, James A. Cranford, and Carol J. Boyd. “Illicit Use of Specific Prescription Stimulants Among College Students: Prevalence, Motives, and Routes of Administration.” *Pharmacotherapy* 26, no. 10 (2006): 1501–510. Accessed August 21, 2019. doi:10.1592/phco.26.10.1501.

71 Kushlev, Kostadin, Jason D.e. Proulx, and Elizabeth W. Dunn. “Digitally Connected, Socially Disconnected: The Effects of Relying on Technology Rather than Other People.” *Computers in Human Behavior* 76 (2017): 68–74. Accessed August 21, 2019. doi:10.1016/j.chb.2017.07.001.

Therefore, there is a cycle of social pain: excessive indulgence in technology leads to social disconnections; this lack of social network encourages the use of quick solutions to relieve their social pain on their own through entertainment and technology. Because this quick solution does not increase the individual's social network, their social pain intensifies and quick fixes such as opioids are made to seem more attractive.

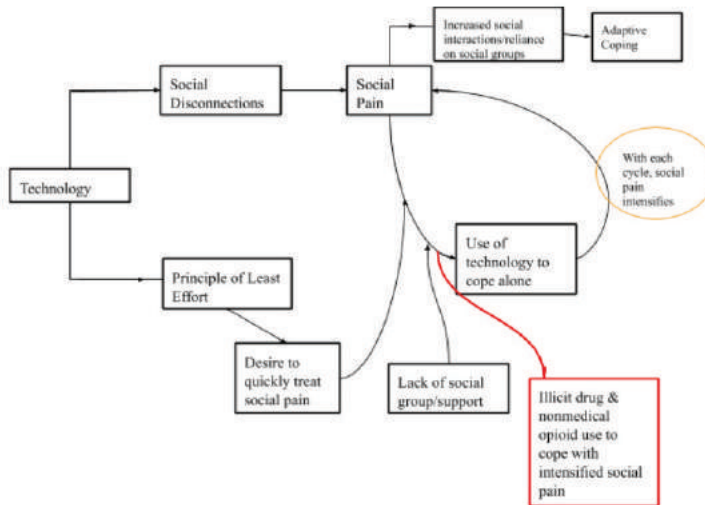


Figure 3.
Yoon, 2019⁷²

This may explain why the new victims of the current fentanyl epidemic are young adults aged 25–34.⁷³ Young adults are the greatest users of modern technology and, as noted in the interview, view technology as a distraction that helps them positively cope with pain. However, they also feel the pressure to suppress their pain and chase the unrealistic depiction of happiness while loneliness and a sense of disconnection loom over their increasingly stressful world that idolizes efficiency. Opioids and other illicit drugs provide a perfect solution to their problems by allowing them to cope quickly with their pain. Therefore, as the diagram above demonstrates, there is not a singular mechanism that drives opioid addiction; instead it is a complex web of interconnected factors.

Ultimately, there are three takeaways from this analysis of science and technology in explaining why people turn towards opioids. First, cyborg

⁷² Yoon, Su Min “The Invisible Culture of Pain and the Opioid Crisis” (Essay, 2019).

⁷³ Spence, Merianne, Margaret Warner, and Brigham Bastian. “Drug Overdose Deaths Involving Fentanyl, 2011–2016.”

technoculture encourages greater control of human qualities, including our own emotions.⁷⁴ Second, the growing use of technology in daily lives limits social interactions, making individuals more vulnerable to social pain.⁷⁵ Third, because we are accustomed to technology providing us with quick solutions, we are more inclined to use opioids rather than our social networks to easily solve our complex inner problems, which intensifies social pain.⁷⁶ Therefore, it is this culture of social disconnection, desire for quick, efficient solutions, and unbridled desire to escape the limitations of the body that attracts individuals to opioids.

5. Discussion and Conclusion

In this research, I argue that the growing role of social pain as one of the main motives in why young adults are increasingly abusing opioids. Analyzing interview responses and STS literature reveals that the principle of minimal effort not only influences how we view technology, but also how we cope with pain and stress. This desire to seek quick solutions to complex internal struggles highlights why people are increasingly turning towards opioids to solve a multitude of problems. Coupled with limited social interactions, individuals eventually become entrapped in a cycle of intensifying social pain that makes them more vulnerable for opioid abuse.

However, it is important to note that technology-induced social pain is not the only driver of the opioid crisis. As previously discussed in the literature review, the opioid epidemic is not a singular problem with a simple solution, which explains why previous and current efforts to solely limit the prescription opioid supply or to criminalize abusers does not work because it fails to account for the root causes. Instead, the opioid crisis is driven by an intricate network of socioeconomic factors, medicalization of addiction, social pain, and stress. To curb this crisis, researchers need to aggressively focus on identifying social factors and systematic errors that might be pushing individuals towards opioid abuse.

The current opioid crisis is not only characterized by the overprescription of painkillers but also by the growing vulnerability to social pain. Many

74 Kunzru, Hari. "You Are Cyborg." *Wired*. December 15, 2017. Accessed August 22, 2019. <https://www.wired.com/1997/02/ffharaway/>.

75 Kushlev, Kostadin, Jason D.e. Proulx, and Elizabeth W. Dunn. "Digitally Connected, Socially Disconnected: The Effects of Relying on Technology Rather than Other People." *Computers in Human Behavior* 76 (2017): 68–74. Accessed August 21, 2019. doi:10.1016/j.chb.2017.07.001.

76 Ibid.

people are simply unaware of the dangers of social isolation and of using technology rather than human interactions to cope with their loneliness, anxiety, or other emotional strain because such quick fixes have become normalized in our current society. Therefore, the most plausible way to resolve this issue is to educate the population on the dangers of technology-induced social isolation and to promote positive coping mechanisms. The best way to disrupt the association of quick fixes as “good” is to replace it with another idea: that there are healthy ways to cope with social pain, although these methods may take longer and require more effort. It is also important to institute counseling centers where people can have easy access to social groups. The main goal of these counseling centers is to make reliable human interactions easier to access than the temporary safe-haven provided by technology, and eventually motivate individuals to seek human interactions rather than the virtual world, even though it may entail more time and effort.

Future research should focus more on elucidating the role of biomedical research in continuously developing more potent, addictive painkillers. Understanding why there is a constant demand for the development of novel synthetic opioids may help us find appropriate substitutes while regulating the exploration of this dangerous research. It is also important to study the illicit black market itself—why are drug dealers contaminating their supplies with potent fentanyl, and should the knowledge of producing such dangerous chemicals be regulated? Are illicit drug dealers “accessible doctors” for the poor who cannot afford proper medical attention? If healthcare were universally available to every individual, would there still be a drug crisis? Although finding the answers to these questions is difficult, understanding the illicit black market will give greater insight into causes of drug use, international supply chain of illicit opioids, and the individuals who use them and create them, all of which are critical to uncovering the ever-changing nature of the opioid crisis.

Ultimately, the opioid crisis is not simply a mechanical error in the human body. Rather, it is a story of pain that warns us of how deep racism, classism, medicalization, and blind faith in science have metastasized. Social pain is a side effect of technological development, and every generation from here on out will be increasingly vulnerable to it. We cannot continue to blindly embrace the comforts of quick solutions while seeking a more bearable and less painful fantasy. We need to take the chance and connect to our imperfect yet beautiful reality, even though it may be a bit more painful, difficult, and uncomfortable.

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Adverse Selection in the Chinese Healthcare System

Reducing Information Asymmetry to Optimize the Utilization of Hospital Capacity

Thalia Ou

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1. Introduction

The medical capacity of a hospital refers to that hospital's medical technology, medical equipment, and medical quality. The Ministry of Health of People's Republic of China classifies hospitals into three tiers—primary, secondary, and tertiary. Hospitals are classified into these tiers in accordance with their ability to provide medical care and training for future doctors pursuing their medical education, and conduct medical research. The Ministry of Health defines a secondary hospital as “a regional hospital that provides comprehensive medical care, medical education, and medical research for the region,” and a tertiary hospital as “a cross-regional hospital providing comprehensive and specialized medical care with a high level of medical education and research functions.”¹ Secondary and tertiary hospitals are further classified into sub-groups: Grade A, Grade B, and Grade C according to their medical capacity.

Primary hospitals are inferior to secondary and tertiary hospitals in medical capacity, and are designed to provide primary care to the local community. Primary care is the routine, most basic care patients receive. In China, primary hospitals include village clinics and township hospitals

1 Li, Xingming, Jianshi Huang, and Hui Zhang, “An Analysis of Hospital Preparedness Capacity for Public Health Emergency in Four Regions of China: Beijing, Shandong, Guangxi, and Hainan,” *BMC Public Health* 8, no. 1 (2008).

in rural areas and community health centers (CHCs) in urban areas.² In rural village clinics, primary care is delivered by unlicensed village doctors; in rural township hospitals and community health centers, primary care is delivered by general practitioners (GPs).³ While primary hospitals provide only primary care, secondary and tertiary hospitals provide both primary care and specialized care. They administer specialized care through distinct departments. Examples of common departments include ophthalmology, neurology, orthopaedics, and cardiology. In China, the quality of care offered in a hospital may differ significantly across departments. In other words, hospitals have their unique strengths and weaknesses.

China's healthcare system functions differently from that of much of the western world. In North America and most of western Europe, the primary care system functions as a gatekeeper. Patients can only access specialized care in higher-level hospitals or at the private offices of specialized doctors with a referral from their primary care doctors. On the other hand, China's primary care system does not function as a gatekeeper. This leads to a fragmented healthcare system in China where a significant portion of patients seek primary care in secondary and tertiary hospitals.⁴ The result is that secondary and tertiary hospitals are overburdened while primary hospitals struggle to attract patients.⁵

This problem is exacerbated by Chinese patients' mistrust in primary hospitals. Patients who have never visited a primary hospital tend to believe that the quality of care in secondary and tertiary hospitals is higher than that in primary hospitals.⁶ This perception, however, is false. A study published in the *International Journal for Equity in Health* found that when patients have actually sought care in a primary hospital, they perceive primary care quality in public primary hospitals to be higher than in public secondary and tertiary hospitals.⁷ Another study conducted by BMC Health Services

2 "International Health Care System Profiles," China: International Health Care System Profiles, Accessed September 8, 2019. <https://international.commonwealthfund.org/countries/china/>

3 Ibid.

4 Dan Wu and Tai P. Lam, "Underuse of Primary Care in China: The Scale, Causes, and Solutions," *The Journal of the American Board of Family Medicine* 29, no. 2 (January 2016): 240–47. <https://www.jabfm.org/content/29/2/240>

5 Ibid.

6 Ibid.

7 Wenhua Wang, Elizabeth Maitland, Stephen Nicholas, Ekaterina Loban, and Jeannie Haggerty, "Comparison of Patient Perceived Primary Care Quality in Public Clinics, Public Hospitals and Private Clinics in Rural China." *International Journal for Equity in Health* 16, no. 1 (March 2017). <https://www.researchgate.net/publication/>

demonstrated that CHCs provide better quality primary care when compared with secondary and tertiary hospitals.⁸

From this it can be seen that patients trust secondary and tertiary hospitals more not because of an actual disparity in quality, but rather because the bigger a hospital is, the more famous it is, and in the public mind fame vouchsafes for quality. As more patients visit the high level hospitals, these hospitals become even more famous, and attract more patients. On the other hand, because few patients visit primary hospitals, few patients ever realize that the quality of primary care in primary hospitals is high. As a result, this mistrust continues, preventing primary hospitals from attracting more patients. In short, secondary and tertiary hospitals become more famous because of their current fame, while primary hospitals lose the opportunity of becoming famous because of their current lack of fame.

Patients' choice of hospitals based on classification and fame is the result of information asymmetry in the Chinese healthcare market. Information asymmetry refers to situations in which one party of an economic transaction possesses greater knowledge than the other party. There are two types of information asymmetry: adverse selection and inverse adverse selection. Adverse selection occurs when sellers have more information than buyers on the quality of the goods and services in that market. Inverse adverse selection occurs when buyers have more information than sellers. The situation of the Chinese healthcare market is specifically adverse selection: because patients are not very informed about the quality of each hospital, they have no other criteria to rely on except for hospital classification and fame when choosing hospitals.

Information asymmetry harms both the healthcare system and the patients. It harms the healthcare system because it overburdens higher level hospitals, especially tertiary hospitals, and underutilizes primary hospitals. It harms the patients because patients lose the opportunity of obtaining better primary care in primary hospitals, and because they suffer from long waiting time in higher level hospitals. In Part V, I will propose two solutions to information asymmetry in the Chinese healthcare market: government action and innovation of online hospital appointment registration platforms.

320198717_Comparison_of_patient_perceived_primary_care_quality_in_public_clinics_public_hospitals_and_private_clinics_in_rural_China

8 Ruwei Hu, Yu Liao, Zhicheng Du, Yuantao Hao, Hailun Liang, and Leiyu Shi, "Types of Health Care Facilities and the Quality of Primary Care: a Study of Characteristics and Experiences of Chinese Patients in Guangdong Province, China." *BMC Health Services Research* 16, no. 1 (February 2016). <https://bmchealthservres.biomedcentral.com/articles/10.1186/s12913-016-1604-2>

2. Methodology

In this paper, I will conduct most research based on secondary sources. I will first research the concepts of adverse selection and inverse adverse selection to construct a literature review on information asymmetry in Section 3. In the literature review, I will include examples of real-life markets characterized by both types of information asymmetry, and quote from previous studies conducted by economics experts, including professionals who coined the concepts of adverse selection and inverse adverse selection. In Section 4, I shall research patients' psychology when choosing the medical provider. I will utilize past surveys that reveal what characteristics patients value in medical provider and hence their preferences regarding hospital level. I will also make connections to price elasticity of demand, using information from academic websites. In Section 5, I provide original analysis of the Chinese healthcare system based on economic theories and patients' psychology elaborated upon in previous sections. I will provide information and insights on online registration platforms through incorporating both my first-hand observation of these platforms and information disseminated by these platforms through official channels. In Section 6, I propose methods to remedy inverse adverse selection in the Chinese healthcare system, considering the unique context of the Chinese economy. In my paper, I use a combination of sources by persons and institutions based in China and other countries, but all sources are in English.

3. Literature Review

i) Adverse Selection

Adverse selection refers to circumstances in which sellers possess more information on the traded products than buyers do.⁹ In this case, before buyers have started using a product, they are uncertain about the quality of that product.¹⁰ As a result, buyers have to estimate the quality of products when making purchases. Because of normal distribution, it is most likely that a randomly selected product is of average quality. Therefore, buyers estimate that the product is of average quality and are thus willing to pay, on

9 Prateek Agarwal, "Adverse Selection," *Intelligent Economist*, April 10, 2019. <https://www.intelligenteconomist.com/adverse-selection/>

10 Arun Sundararajan, "The Shifting Landscape of Regulation and Consumer Protection," in *The Sharing Economy: the End of Employment and the Rise of Crowd-Based Capitalism* (Cambridge, MA: The Mit Press, 2017)

average, a price commensurate with the value they would get from an average quality provider.¹¹ Buyers' perception of the average quality of products in a particular market is shaped by their past experiences in that market. If the buyer finds the average quality of the products she has bought in this market in the past to be high, the buyer would expect the quality of the item she is about to purchase to be high as well. As a result, she will be willing to pay more for the product than she would if the average product quality had been lower up to the point of the transaction, and vice versa.

From the sellers' perspective, the revenue that a product generates depends not only on the quality of that product, but more saliently on the average quality of the products in that market. As a result, if a seller provides goods lower in quality than the market average, she will reap the benefit of buyers' willingness to pay due to the market's good overall quality; if she provides goods higher in quality than the market average, buyers would be no more willing to pay than they would have been if the quality the seller offers were lower, and the seller alone bears the high cost of offering high quality products. Therefore, in a market where sellers are more informed about the quality of products than buyers are, sellers have an incentive to sell low quality products. As George A. Akerlof, who first introduced the theory of adverse selection, put it:

There are many markets in which buyers use some market statistic to judge the quality of prospective purchases. In this case there is incentive for sellers to market poor quality merchandise, since the returns for good quality accrue mainly to the entire group whose statistic is affected rather than to the individual seller. As a result there tends to be a reduction in the average quality of goods and also in the size of the market.¹²

By "many markets" and "in this case," Akerlof refers to markets in which buyers are not informed about the quality of products. "Market statistic" in Line 1 refers to the average quality of products in the market, and "entire group" in Line 4 refers to the entire cohort of sellers in a particular market.

A classical example of adverse selection is the market for second-hand cars. This example was given by Akerlof in his 1970 paper *The Market for "Lemons": Quality Uncertainty and the Market Mechanism*. Lemons refer to

11 Ibid.

12 George A. Akerlof, "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism," *The Quarterly Journal of Economics* 84, no. 3 (Aug 1970): 488–500 https://www.jstor.org/stable/1879431?seq=1#metadata_info_tab_contents

low quality second hand cars. In the market for second hand cars, buyers are not sure about the status of the cars. Sellers know whatever flaws the cars might have, which are not apparent to the buyers. As a result, the price a buyer is willing to pay for a car is influenced by the average quality of all the cars in the market. From the perspective of a seller, the revenue the seller earns from a car is no longer the sole result of the quality of that car. Therefore, given that the cost of providing a high quality car is higher than providing a low quality one, it is profitable for sellers to lower the quality of cars they offer. As the average quality of cars in the market declines, buyers' willingness to pay a premium price for an average car decreases, forcing sellers to lower prices. This market outcome of lower quality and lower price holds true in almost all markets in which buyers are not sure of the quality of the products. An exception to this will be dealt with in Part III and Part IV.

In addition to the fact that adverse selection impacts many markets, the effect of adverse selection is also long-term. When the revenue sellers can get from buyers for each single product decreases, high quality providers are out-competed by their lower quality counterparts because the cost of producing high quality products is higher than producing low quality products. As the high quality providers withdraw from the market, the quality of products in the market becomes even lower. A cycle is then created: lower quality drives down prices, and the lowered price again drives down quality, and so on. This cycle repeats itself until the only dealers left in the market are the lowest quality providers who are able to sell at a low price.¹³

As Prateek Agarwal, former Economics student at the University of South Carolina and creator of *The Intelligent Economist*, summed it up: "Adverse selection leads to ill-informed, poor decisions on the part of buyers, which leads to inefficiency in the price of goods and services within the market."¹⁴ On top of leading to price deflation, adverse selection pushes the quality of goods and services below the socially desirable level.

ii) Inverse Adverse Selection

Inverse adverse selection refers to situations in which buyers have more information on the value of the traded products than sellers. Inverse adverse selection often occurs in second-hand markets of valuable products. This is because second-hand markets for valuable goods satisfy the two conditions needed for inverse adverse selection to occur. The first condition is that determining the intrinsic value of the market's products must require

13 Sundararajun, *The Sharing Economy*.

14 Agarwal, "Adverse Selection."

expertise. Second-hand luxury markets satisfy this condition, because since luxury goods are not necessities, it is hard for a person to intuitively perceive the direct benefit luxury goods can bring him or her. Experts can tell the value of luxury goods because they know how to accurately judge the quality of the products and are familiar with market trends.

The second condition is that expertise in the market must generally be owned by buyers and not sellers. In second-hand markets, most sellers do not engage in the trade of a specific product as a career. Instead, they only attempt to dispose of things they don't want anymore. On the other hand, many buyers in second-hand markets for luxury goods are expert collectors. Many expert collectors are attracted to these markets because trading luxury goods involves large amounts of money and therefore have the potential to generate large amounts of returns.

To sum it up, because judging the value of second-hand valuable products requires expertise and expertise is possessed by buyers and not sellers, second-hand markets for valuable products begets information asymmetry, with buyers having more information than sellers on the value of the traded products, i.e. inverse adverse selection.

Two examples of such markets are the second-hand gemstone market and the second-hand artwork market. This observation was first made by Giuseppe Dari-Mattiacci, Sander Onderstal, and Francesco Parisi, who wrote in their 2011 paper, *Inverse Adverse Selection: The Market for Gems*, that

This [inverse adverse selection] is often the case for goods of uncertain value, such as artworks, or for sales between a diamond expert and an individual seller.¹⁵

The second-hand markets for artworks and for gemstones both satisfy the two conditions discussed before. First, it is hard for non-experts to tell the quality of gemstones and artwork. Second, in the gemstone market and the artwork market, buyers in most transactions are expert collectors while sellers are not. Buyers in most transactions are expert collectors because collectors are attracted by the economic prospects of gemstone or artwork dealing and because while an expert collector tends to buy a large number of gemstones or a large collection of artwork, a non-collector would not be interested in buying a lot of those products. Sellers in most transactions are non-experts because as mentioned before, they simply want to get rid

15 Giuseppe Dari-Mattiacci, Sander Onderstal, and Francesco Parisi, "Inverse Adverse Selection: The Market for Gems," *Tinbergen Institute* 2011. <https://papers.tinbergen.nl/11017.pdf>

of an item they don't want. These two conditions make gemstones and artwork two products that are prone to inverse adverse selection. Therefore, Dari-Mattiacci, Onderstal, and Parisi use "the gem market" as an umbrella term for all markets in which inverse adverse selection tends to take on a stronghold.

Since sellers in an inverse adverse selection market are not informed about the quality of the products, they tend to set high prices for both higher-quality products and lower quality products in order to avoid the possibility of selling something below its actual value. As a result, the difference in prices for high quality goods and low quality goods is smaller than the difference between their quality, and smaller than it would have been in a normal market. As Dari-Mattiacci, Onderstal, and Parisi noted in their paper,

Sellers may be induced to ask very high prices, suspecting that if an (informed) buyer shows interest in what they are selling, the good that is being sold must have some hidden quality of which they are not aware.¹⁶

Unlike sellers, buyers are informed about the products and can distinguish between high quality and low quality products. Because the price of both high-quality and low-quality products are high, they only buy the high quality products. This leads to the result observed by Dari-Mattiacci, Onderstal, and Parisi:

Unlike in the lemons market, in the gems market the selection affects low-quality goods, leaving only high-quality goods on the market and pushing up prices. The race to the bottom in quality and prices observed in the lemons market turns into a race to the top in both quality and prices in the gems market.¹⁷

Indeed, almost all of the products that change hands in an inverse adverse selection market are of high-quality. So when sellers withdraw unsold products from the market, they are actually withdrawing the low-quality products, although they might not know it. As low quality goods are withdrawn and high quality products remain, the average market price becomes higher. As a result of this new higher price, among the remaining products, buyers choose to buy high quality ones that are worthy of their high prices. The cycle self-perpetuates. This outcome is exactly opposite to that of adverse

16 Ibid.

17 Dari-Mattiacci, Onderstal, and Parisi, "Inverse Adverse Selection."

selection markets, in which information asymmetry favoring sellers pushes down prices and the quality of products.

However, since Dari-Mattiacci, Onderstal, and Parisi's paper was published in 2011, information asymmetry has been gradually decreasing in many second-hand markets for luxury goods. This is because of the emergence of third-party online platforms that serve as middlemen and provide both sellers and buyers with expert knowledge on the quality of products. For example, *TheRealReal* is an online platform founded in 2011 that buys and resells second-hand gemstones and watches.¹⁸ It recruits experts to judge the quality of gemstones and watches and price them accordingly.¹⁹ *TheRealReal* then adds a commission fee to the value determined by the experts and discloses the final sale price on its website. Unlike second-hand markets of luxury goods before the emergence of third party platforms, the final price in this scenario reflects the value of the item and therefore fills the gap of knowledge between buyers and sellers.

The Material Box is another such example. Founded in 2012, it is a "styling service delivering pre-owned designer items."²⁰ Like *TheRealReal*, *The Material Box* authenticates and prices items, and it profits from a commission fee. Unlike *TheRealReal*, *The Material Box* is not limited to gemstones and watches. Rather, it trades all "branded luxury closet items" including handbags, outfits, and shoes.²¹ As a result of third party online platforms like *TheRealReal* and *The Material Box*, buyers and sellers are increasingly being put on an equal footing in transactions of luxury items. Therefore, the effect of inverse adverse selection has been decreasing in recent years.

4. Patient Choice of Healthcare Provider In China With Regard To Facility Level

In all markets, an increase in the price of a product leads to a decrease in the quantity of products demanded. However, given a fixed percentage of increase in price, the decrease in quantity demanded varies for different types of goods and services. To measure how sensitive the demand for a

18 "About," *The RealReal*, Accessed September 8, 2019. <https://www.therealreal.com/about>.

19 Ibid.

20 "Material World: Personal Stylists: Pre-Owned Designer Fashion: Clothes Boxes." *Material World*, Accessed September 8, 2019. <https://www.materialworld.co/>

21 Yukari Mitsuhashi, "Material Wrld Raises \$9 Million to Sell Used Luxury Items Online," *VentureBeat*, April 4, 2016. <https://venturebeat.com/2016/03/31/material-wrld-raises-9-million-to-sell-used-luxury-items-online/>

product is to the price of that product, Alfred Marshall introduced the term *price elasticity of demand* (Ed) in 1890. Price elasticity of demand is defined as the percentage change in the quantity demanded of a good or service divided by the percentage change in the price, so the larger Ed is, the more sensitive the demand is to changes in price. A product is said to have an inelastic demand if $Ed < 1$. For Ed to be less than 1, the percentage change in the quantity must be smaller than the percentage change in the price. This means that the product is a necessity and many people buy it even if the price rises. A product is said to have an inelastic demand if $Ed < 1$. This means that the product is a luxury and many people stop buying it when the price rises. This is because the product is not essential to survival and people can live without it. A product is said to have a unit elastic demand if $Ed = 1$. This means that people's sensitivity to price changes of that product is medium.

The demand for healthcare has always been inelastic. In 2017, Yu Hao found that the price elasticity of demand of healthcare in China is between 0.42 and 0.58.²² In comparison, the price elasticity of demand of gasoline is 0.7. Gasoline has an inelastic demand because it is a necessity for all car-owners. The price elasticity of demand of fish, which is almost a necessity in the Chinese cuisine, is 0.5. The price elasticity of demand of restaurant meals and foreign vacations are 2.3 and 4.0, respectively. Restaurant meals and vacations to other countries have an elastic demand because they are not essential to people's lives. This comparison shows that Chinese people are more sensitive to price changes of healthcare than they are to that of gasoline, and that they are equally sensitive to price changes of healthcare and that of fish, indicating that people are highly insensitive to the price of healthcare. This is because healthcare is indispensable for the survival and well-being of human beings, so even when prices rise, people still choose to purchase it.

Chinese patients' irresponsiveness to the price of healthcare services manifests itself in patients' decisions. Chinese patients tend to seek care in secondary and tertiary hospitals even though healthcare in those high-level hospitals is more expensive than in primary hospitals. A survey conducted by Tai Pong Lam and his associates among Chinese patients in 2015 found that 70% of the respondents preferred secondary and tertiary hospitals for first-contact care.²³ This is because patients consider the quality of care to be

22 Hao Yu, "China's Medical Savings Accounts: an Analysis of the Price Elasticity of Demand for Health Care," *The European Journal of Health Economics* 18, no. 6 (2017): 773–85 <https://www.ncbi.nlm.nih.gov/pubmed/27650358>

23 Dan Wu, Tai Pong Lam, Kwok Fai Lam, Xu Dong Zhou, Kai Sing Sun, "Health Reforms in China: the Public's Choices for First-Contact Care in Urban Areas," *Family*

more important than price. Tai Pong Lam and his associates illustrated this idea in their 2017 report *Health Reforms in China*:

In the decision-making process, compared to cost factors like medical expenses and waiting times, participants attached greater emphasis on organizational characteristics.²⁴

In their study, “organizational characteristics” refer to “sophisticated medical equipment, reputation of the facility, and average education of doctors.” Patients choose to seek care in secondary and tertiary hospitals because they preconceive healthcare in high level hospitals to be better than that offered in primary hospitals, and are so convinced of healthcare’s importance that they are willing to pay more for higher quality care. As it turns out, however, Chinese patients are wrong in their preconception. In 2017, the World Health Organization conducted a survey among Chinese patients who had already visited both primary hospitals and higher level hospitals during the past year. On a five point scale, the 3435 respondents were asked to rate the primary hospitals and the higher level hospitals that they had visited on five domains: prompt attention, communication and autonomy, dignity and confidentiality. The result was that primary hospitals were able to earn ratings higher than hospitals on all five domains.²⁵ In another survey conducted in Guangdong Province by BMC Healthcare Services Research using the Chinese Primary Care Assessment Tool (PCAT), patients who had visited both community health centers (CHCs) and higher level hospitals rated CHCs higher than secondary and tertiary hospitals on first contact-access, ongoing care, comprehensiveness-services available, and community orientation.²⁶

This false preconception, combined with the fact that patients consider quality of care to be more important than price when choosing a healthcare provider, leads to a most peculiar outcome of information asymmetry in the healthcare market, which will be discussed in Part IV.

Practice 34, no. 2 (January 24, 2017). <https://academic.oup.com/fampra/article/34/2/194/2949262>

24 Ibid.

25 Wang, Maitland, Nicholas, Loban, and Haggerty, “Comparison of Patient Perceived Primary Care Quality.”

26 Hu, Liao, Du, Hao, Liang, and Shi, “Types of Health Care Facilities and the Quality of Primary Care.”

5. Information Asymmetry in the Chinese Healthcare Market: Adverse Selection or Inverse Adverse Selection?

In the healthcare market, sellers have more information on the quality of products than buyers do. The “sellers” are the healthcare providers, namely people running hospitals and health centers; the “buyers” are patients; the “products” are healthcare services and medicine. Healthcare providers are very informed of the quality of the products because they run the hospitals and the quality of healthcare is *determined* by them. On the other hand, patients are not informed about the quality of healthcare provided by each hospital because they are not part of the decision making process that determines what kind of healthcare should be delivered in each hospital, nor would sellers attempt to deliver the information on healthcare quality to them because every provider, in an effort to increase profits, seeks to convince patients that the quality of healthcare provided by their hospital is high, no matter if that is true or not. This information asymmetry with sellers being more informed places the buyers and sellers in the Chinese healthcare market in the same situation as that in an adverse selection market, as discussed in Part II Section i).

Uncertain about the quality of care offered by each hospital, patients turn to rely on the reputation, classification, and the ranking of hospitals to judge a hospital’s quality and therefore trustworthiness. Intuitively, patients judge famous, tertiary, top-ranking hospitals to be the best in quality. Although the cost of healthcare increases as the classification level becomes higher, patients still choose to seek care in high level hospitals when they perceive the quality of care to be better there, as has been discussed in Part III.

Although buyers and sellers in the Chinese healthcare market are in the same situation as that in an adverse selection market, this choice of patients is contrary to the usual behavior of buyers in a market with adverse selection. As discussed in Part II, Section i), in a market where sellers have more information than buyers, buyers tend to purchase cheap things when they are uncertain about the quality of the product. Rather, patients behave like buyers in a market dominated by inverse adverse selection: they tend to choose the more expensive option. Just like in an inverse adverse selection market, this choice pushes up the price and makes lower-quality providers withdraw from the market. I will analyze this impact from the perspective of price and from the perspective of quality separately.

From the aspect of price, patients’ choice to seek care in high level hospitals despite high costs incentivizes high level hospitals to set high prices because firstly, hospitals do not need to worry that the demand might drop if they raise prices; and secondly, secondary and tertiary hospitals see the high

demand for their healthcare services as a signal that patients perceive high value in their service and therefore do not want to undersell their healthcare service. This is problematic because under the influence of inverse adverse selection, healthcare will become less and less affordable.

From the aspect of quality, patients' gravitation towards high level hospitals drives primary hospitals out of business. This is because primary hospitals cannot attract enough patients to make a profit. In addition to hurting people who work in primary hospitals by making them lose their jobs, this gravitation is problematic because of two other reasons. First, it overcrowds tertiary hospitals. This decreases the quality of care offered by tertiary hospitals, because the medical resources of tertiary hospitals have to be divided among a large number of patients. For example, compared to hospitals that are not overburdened, tertiary hospitals might have to place more beds in one ward and give each individual patient less attention. In addition, patients' experience of seeking care becomes less pleasant because patients suffer from long queues. Second, this gravitation leads to underutilization of the medical capacity of primary hospitals. As has been discussed in Part III, classification does not necessarily provide for quality. Often, when patients have actually visited primary hospitals, they find that primary hospitals offer better care than secondary and tertiary hospitals do. However, because of patients' tendency to behave as if in an inverse adverse selection market, patients do not seek care in primary hospitals, which would not only have saved them money but also brought them better care. In other words, the value primary hospitals could have generated for patients is lost.

This problem is exacerbated by online appointment registration platforms. Online platforms were created to allow patients to register with the department and hospital of their choice before their hospital visit, so that patients do not need to line up in front of the registration desk when they arrive at the hospital. In this sense, online platforms are beneficial because they save time for patients. On the other hand, online platforms exacerbate the problem of overburdening higher level hospitals and underutilizing lower-level healthcare facilities by encouraging patients to register with a high level hospital. They make it more likely for patients to choose a high level hospital because firstly, the proportion of high level hospitals included in these platforms is far higher than the percentage of low level hospitals included; and secondly, these platforms rank healthcare facilities based on their classification and popularity. The rest of Part IV discusses these two problems of online appointment registration platforms, with particular focus on two platforms: Ping An Good Doctor and Hospital Registration Web (yīyuàn guàhào wǎng in Chinese). Ping An Good Doctor was released in 2014 by China Ping An Group, an important member of the Chinese Internet

business segment.²⁷ Hospital Registration Web was released in 2017 by Youyidao, a technology company based in Chongqing Province.²⁸ Both platforms offer hospital registration service throughout China. I choose to focus on these two platforms because although there are many other similar platforms, these are two of the most prominent hospital registration platforms in China and are typical of registration platforms.

By 2009, all public tertiary hospitals had been included in some online registration platform.²⁹ However, patients can only register with a limited number of secondary hospitals online, and the proportion of primary hospitals that are included in the online registration platforms is even smaller. By 2011, China had 1,350 public tertiary hospitals, 6,034 secondary hospitals and 918,003 primary hospitals.³⁰ Of all the primary hospitals, 32,860 were urban community health centers.³¹ Ping An Good Doctor works with over 1,200 tertiary hospitals, which is about 90% of all tertiary hospitals.³² On the other hand, the number of primary hospitals that Ping An Good Doctor collaborates with is 2,000.³³ This means patients can only register with 0.2% of all primary hospitals online. A simple calculation shows that 99% of the hospitals that are not included in Ping An Good Doctor are primary hospitals. This happens because hospital registration application companies lack the incentive to include primary hospitals. Since patients are not very interested in primary hospitals in the first place, including primary hospitals will not help attract users. On the other hand, registration application companies have an incentive to include tertiary hospitals because it helps them attract users and therefore earn more money.

27 “Ping An Good Doctor,” Crunchbase. <https://www.crunchbase.com/organization/ping-an-good-doctor>.

28 “Chongqing Youyidao Technology Co., Ltd.,” *Qimai Statistics*. <https://www.qimai.cn/detail/publisher/id/1289112824/device/iphone/country/cn>

29 MinMin Zhang, CongXin Zhang, QinWen Sun, QuanCai Cai, Hua Yang, and YinJuan Zhang, “Questionnaire Survey about Use of an Online Appointment Booking System in One Large Tertiary Public Hospital Outpatient Service Center in China.” *BMC Medical Informatics and Decision Making* 14, no. 1 (September 2014). <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4059480/>

30 “China’s Healthcare System—Overview and Quality Improvements,” *Swedish Agency for Growth Policy Analysis*, no.3 (May 2013). <https://www.tillvaxtanalys.se/download/18.5d9caa4d14d0347533bcf93a/1430910410539/direct>

31 Ibid.

32 “Ping An Good Doctor Establishes Strategic Partnership with Jointown,” *Markets Insider*, 2018. <https://markets.businessinsider.com/news/stocks/ping-an-good-doctor-establishes-strategic-partnership-with-jointown-1027489636>

33 Ibid.

The Hospital Registration Web does even worse than Ping An Good Doctor in incorporating low level hospitals. When Hospital Registration Web users enter “community health center” in the search bar, only 7 results pop up. This is a shockingly small number given that there are 32,860 urban community health centers in China. It means that even when patients intend to register with a CHC, they are discouraged from doing so because they can’t find one that’s near them on the platform.

The exclusion of most primary hospitals from online appointment registration platforms has a significant impact. This is because of two reasons. First, online registration platforms make registration with the hospitals they work with more convenient. This incentivizes patients to choose high level hospitals instead of low level ones. Second, online registration platforms give exposure to hospitals they work with. When platform users are browsing the platforms, hospitals included in the platform are brought to the attention of those users, while the hospitals that are not included—often primary hospitals—lose out in this process.

In addition to the fact that most primary hospitals are not included in online registration platforms, *among the hospitals that are included*, it is *still* much more likely for patients to come across tertiary hospitals than lower level hospitals. This is because whenever a platform generates a list of hospitals, each hospital is ordered based on its level and the number of patients who have registered with that hospital. The Hospital Registration Web uses this ordering method for the “Hospital Ranking” section on its front page. It also orders hospitals this way when patients search for a hospital in the search bar and when patients select a hospital department. Because patients tend to trust high level hospitals, the number of patients who have registered with a high level hospital is almost always larger than that number of a low level hospital. Therefore, this ranking method gives high level hospitals a higher chance of exposure than low level ones. As a result of this increased exposure, more people register with high level hospitals. This creates a positive feedback loop: when more people register with a hospital, that hospital rises in rank, gain more exposure, and in turn see more people register with it.

It has been discussed before that the Chinese healthcare market is plagued by information asymmetry. The market situation is one of adverse selection, with healthcare providers being more informed than patients on the quality of care in each healthcare facility. Yet the market outcome is one of inverse adverse selection, meaning that patients tend to choose high level hospitals over low level ones and healthcare price increases. Online hospital registration platforms make the effect of information asymmetry in the Chinese healthcare market even more prominent. They divert patients away from primary hospitals and concentrate them in tertiary hospitals. Perhaps more

subtly, the ordering method itself also poses a threat. The “ranking by hospital level” reinforces people’s perception that hospital level is a good measurement of quality of care. It seems to validate patients’ choice of healthcare provider, making it even harder to remedy the inefficiency in the utilization of medical capacity. However, knowing how adverse selection and its inverse are precipitated and reinforced in the Chinese healthcare market, we might still be able to devise a remedy after all.

6. Remediating inverse adverse selection in the Chinese Healthcare Market

To optimize the utilization of hospital capacity, it is necessary to target at least one of the factors that fomented this problem. The solution will have to address either the adverse selection situation of the healthcare market or the inverse adverse selection behavior of the patients—or both. Given the information asymmetry prevalent in healthcare market, it is almost impossible to reverse patients’ choice of healthcare provider. This is because healthcare will always be a necessity, meaning that patients will always be insensitive to price and choose the provider that they perceive to be of high quality. Therefore, we must seek to attenuate the adverse selection that caused patients to think that higher level hospitals are better in the first place. The key is to reduce information asymmetry, i.e. make patients better informed about the quality of care. In Part V, I lay out the measures that could be taken by the government and by online appointment registration platforms to achieve this end.

The government could reduce information asymmetry by funding more nationwide investigations of the quality of care provided by all levels of healthcare facilities. These investigations could be carried out by giving patients surveys at healthcare facilities and by deploying standardized patients. Standardized patients are medical professionals trained to simulate real patients in clinical settings and rate the care that’s administered on them using a checklist. This dual approach is commendable because some might doubt the reliability of investigation results based solely on surveys, claiming that patients are not medical professionals and cannot discern small differences in the quality of care.

After gathering data on the quality of care of China’s healthcare facilities, the government could analyze the data and determine the strength of each hospital. The government could then disseminate these conclusions by setting up billboards in neighborhoods. This will benefit patients because then patients will know which healthcare facility to go to when they need care in a specific area. When a mother seeks care for her sick child, she knows which

hospital is best at pediatrics. When a person has an infected eye, she knows which hospital offers the best ophthalmological treatment in the city. When a person has a cold, she knows that she can get the best care in a primary hospital.

This government approach of disseminating information will not only benefit the patients but also improve the entire healthcare industry in two major ways. First, in the status quo, patients distrust primary hospitals and seek care in big hospitals even when they don't need specialized care. As a result, primary hospitals are underutilized while tertiary hospitals are overburdened unnecessarily. Government dissemination of information will drastically increase the likelihood that patients seek primary care in primary hospitals. Second, in the status quo, patients who are really in need of specialized care hurry to the few top tertiary hospitals that are said to have the best quality of care *in general*. However, as I have pointed out in Part I, because the quality of care differs across departments in Chinese hospitals, this "general quality of care" of a hospital does not accurately predict the quality of a specific category of care that a patient can get in that hospital. The result is that while hospitals that have the best "general quality of care" are overburdened, the best departments in other hospitals are underutilized. Under this new government approach, patients will likely choose hospitals that are the best at offering the specific category of care they need. These positive outcomes can likely be achieved because people generally find empirical data convincing.

In the long run, the Chinese government may establish gatekeeping as a mandatory practice. Under the gatekeeping system, general practitioners (GPs) will serve as gatekeepers and decide which patients need to see specialists and which don't. A patient will need a referral from a GP to see a specialist. A gatekeeping system will completely eliminate the inefficient use of medical resources that arises from patients' mindset. However, this will not be feasible until this mindset has become less entrenched. This is because if patients deeply believe that higher level hospitals provide higher quality care, they will likely ask general practitioners for referrals even when they don't need specialized care. GPs will then have to refuse. As a result, patient-doctor relationship will be strained.

Online appointment registration platforms can also take measures to improve the Chinese healthcare system. First, online appointment registration platforms should work to include more primary hospitals. This will give more exposure to primary hospitals and eliminate time efficiency of registration as a reason for choosing high level hospitals. Second, online registration platforms should change the method of ordering hospitals. When patients select the category of care, the platforms should not list hospitals in an order

based on hospital classification and the quantity of registrations with each hospital. Rather, hospitals should be ordered based on quality of care and their distance from the patient.

The platforms can determine the quality of a specific category of care offered in a hospital by using two methods. First, they can use the data already collected in government investigations, which was discussed earlier in Part V. Second, they can ask platform users to rate the quality of care and give feedback after they have been to their appointments. It is important that patients should only be allowed to rate the quality of care administered by the department that they have visited in that hospital. The purpose of this is to accurately reflect the quality of each category of care provided in each hospital. By using the results from government studies and having patients rate the specific department of hospitals, platforms can list hospitals based on the quality of the specific category of care that a patient needs. The general “hospital ranking” generated by many current online platforms should be phased out. At the same time, online platforms should add “primary care” as a separate category from which patients can choose.

This will solve the problem discussed in Part IV and increase the efficiency of the utilization of healthcare resources. This is because since primary hospitals offer higher quality primary care than higher level hospitals, the top results patients see under the new system when they click on “primary care” will be primary hospitals. As a result, the likelihood that patients seek primary care in primary hospitals will be drastically increased. Furthermore, under this system, when patients do decide to seek care in a tertiary hospital, they will be in a better position to make informed decisions on which tertiary hospital to visit based on the strength of each hospital. This will allow patients to get the best care possible and prevent unnecessary overburdening of the top tertiary hospitals.

The ordering of hospitals should also be based on their distance from patients. When patients select the department, the list generated should show the distance of each hospital from the patient’s location. From the patient’s perspective, this will save transportation time and cost. From the perspective of the entire healthcare market, this measure will divert patient flow to low level hospitals. This is because there are more low level hospitals than there are high level hospitals (See data in Part IV), since a higher level hospital covers a broader geographic area than a lower level one. Tertiary hospitals serve patients in the entire city while primary hospitals serve only the local community. As a result, primary hospitals tend to be closer to patients than tertiary hospitals. In Shanghai, 97% of all residents can reach a primary hospital within 15 minutes, but the percentage of residents who can reach secondary and tertiary hospitals within the same amount of time are much

lower: 38% and 24%, respectively.³⁴ Therefore, this ranking method promotes the ranking of lower level hospitals, increasing the likelihood that patients seek care in primary hospitals. This pattern holds true in other Chinese cities. A 2019 study conducted in Kaifeng also found that travel time is the shortest for people who travel to primary hospitals from residential areas.³⁵

Ordering hospitals by distance has another more indirect benefit. It will shift patients' attention from hospital classification to transportation convenience. In the long run, distance as a factor of consideration when choosing hospitals will rise in importance. In addition, this ranking method will in effect mix primary hospitals, secondary hospitals, and tertiary hospitals, whereas currently the top results are all tertiary hospitals. Hospitals of all levels appearing together will blur the line between different hospital levels in people's minds. Again, this will lessen people's focus on hospital classification. To sum it up, ordering hospitals this way will reshape people's mindset, thereby diverting patient flow to low level healthcare providers and making the utilization of medical resources more efficient.

7. Conclusion

The Chinese healthcare system is plagued by adverse selection: patients who have not yet made their hospital visit are not as informed about the quality of care offered by each hospital as healthcare providers are. This is because healthcare providers have an incentive to overemphasize the quality of care of their own hospital in an attempt to attract patients. Since patients are not sure about the quality of care offered in each hospital before their hospital visit, they intuitively judge the quality of care based on a hospital's fame and level. Because healthcare is a necessity, patients prioritize quality of care over price as a factor of consideration when choosing a hospital. As a result, patients tend to choose tertiary hospitals despite higher medical costs of those hospitals because they perceive care in tertiary hospitals to be better. However, this perception is false. Surveys show that patients who have

34 Xuechen Xiong, Ge Bai, Chao Jin, Yinan Zhou, Haile Chen, Chen Fu, Lingwang Wu, Li Luo, "A Method of Calculating and Visualizing Spatial Accessibility to Health Services Based on the Nearest Distance Method" (article in Chinese), *Chinese Health Resources* 19, no. 4 (2016): 275–279. <http://www.journalchr.com/CN/10.13688/j.cnki.chr.2016.15361>

35 Zhicheng Zheng, Haoming Xia, Shrinidhi Ambinakudige, Yaochen Qin, Yang Li, Zhixiang Xie, Lijun Zhang, and Haibin Gu, "Spatial Accessibility to Hospitals Based on Web Mapping API: An Empirical Study in Kaifeng, China," *Sustainability* 11, no. 4 (February 2019): 1–14. <https://ideas.repec.org/a/gam/jsusta/v11y2019i4p1160-d208184.html>

actually visited primary hospitals and higher level hospitals judge the quality of primary care offered in primary hospitals to be higher than that in higher level hospitals. As a result of this false perception, tertiary hospitals are overburdened while primary hospitals are underutilized.

Online hospital registration platforms exacerbate this problem because of two reasons. First, the percentage of tertiary hospitals included in online platforms is much higher than primary hospitals. This is the result of the deliberate action of online registration application companies. Registration companies do this because high level hospitals are more popular with patients and therefore help attract users. Second, online registration platforms generate lists of hospitals ranked by classification and the number of patients who have registered with each hospital. As a result, tertiary hospitals dominate the top of the lists. These two factors combine to give tertiary hospitals much more exposure than primary hospitals, making them even more famous. This cycle then continues, augmenting the effect of information asymmetry. Both the Chinese government and online hospital appointment registration platforms could take measures to solve this problem.

The Chinese government could collect and disseminate information on the quality of care offered by each department in each hospital. This way, patients will know which hospitals are the best at offering a given category of care and find hospitals best suited to their needs. This will also divert patients who are in need of primary care from tertiary hospitals to primary hospitals. In the long run, the Chinese government could establish a gate-keeping system. Online hospital appointment registration platforms should include more primary hospitals. In addition, online registration platforms should rank hospitals based on distance and the quality of care offered by the department the patient selects. These measures, taken by both the government and online hospital registration platforms, will reduce information asymmetry and attenuate the problem of overburdening tertiary hospitals and underutilizing primary hospitals, and therefore optimize the utilization of hospital capacity.

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Comparison of Determinants of Entrepreneurial Intentions in China and the United States

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Abstract

This study explored the determinants of entrepreneurial intentions according to the Theory of Planned Behavior Model, compared the results in China and the United States, and examined to what extent determinants of entrepreneurial intentions have differed in China and the United States in the past 18 years. This is a quantitative study that uses a correlational design. To ensure the validity, the major source of data is provided by the Global Entrepreneurship Monitor, the world's best study of entrepreneurship. This study selected some indicators of entrepreneurship provided by the GEM as determinants of entrepreneurial intentions according to the Theory of Planned Behavior Model and ran a correlation analysis on Excel to explore the relationships between each indicator and entrepreneurial intentions, followed by the comparison of results in China and the United States. The results suggested: 1) in the United States, perceived feasibility positively, but weakly, influences entrepreneurship intentions, requiring future study, and perceived desirability positively influences every determinant of entrepreneurship intentions; 2) in China, perceived feasibility also positively, but weakly, influences entrepreneurship intentions, and the effect of perceived desirability on entrepreneurship intentions is partial; 3) there are some time nodes, such as 2010, 2006, and 2013, that

may merit further research regarding what happened in these years that influenced entrepreneurial intentions in China. The disparity between results in China and the United States may be partially due to wider economic and political-institutional differences in the two countries, and differences in entrepreneurship framework conditions, including infrastructure, internal market dynamics, and culture.

1. Introduction

Entrepreneurship is a process integrating opportunities, resources, and people (the entrepreneurs) (Timmons & Spinelli, 2009). There is growing consensus across governments and educational institutions that entrepreneurship is a crucial driver of future economic growth, innovation, and job creation (Audretsch, 2002; Thurik, Stam, & Audretsch, 2013). Thus, entrepreneurial intention merits scholarly research.

From the macro level, understanding the motivations of people who want to be entrepreneurs in the future allows schoolteachers and professors, personal consultants and advisors, and government policymakers to understand more deeply and comprehensively how entrepreneurs' motives are molded. Hence, knowledge of the determinants of entrepreneurial intention can help entrepreneurial education enhance the motivation and thus the probability of the consequent economic growth, innovation, and job creation that benefit the whole society.

I selected China and the United States as the two countries incorporated in this study because I would like to be an entrepreneur in one of these two countries in the future. China is where I was born and received primary education, and the United States is where I am currently receiving higher education. They both have profound meaning to me.

2. Literature Review

Entrepreneurship intention showcases the relationship between ideas and action which is important to understand the entrepreneurial process (Bird 1988; Krueger and Carsrud 1993). According to Ajzen (1991), intention indicates the degree to which people show their motivation and willingness to execute the desired behavior.

The motivations for being an entrepreneur and starting one's own company have been analyzed by previous researchers. For example, Scheinberg and MacMillan (1988) identified six different factors leading to the founding of a new company: (1) need for approval, (2) perceived instrumentality of

wealth, (3) degree of communitarianism, (4) need for personal development, (5) need for independence, and (6) need for escape. All of these factors reflect the degree of desirability of entrepreneurship: if all these factors are satisfied, then obviously entrepreneurship is a desirable career choice. Two other studies (Cooper et al., 1989; Reynolds and Miller, 1988) argued that the different reasons for starting a new company could be condensed to only three factors: (1) challenge, (2) wealth, and (3) autonomy. The levels of challenge and wealth indicate the level of capability of an individual to initiate a new business successfully, and the degree of autonomy reflects the level of desirability of becoming an entrepreneur.

Among several conceptual models for understanding entrepreneurial motivations, including the Entrepreneurial Potential Model (Krueger and Brazeal, 1994); the Intentional Basic Model (Krueger and Carsrud, 1993); the Entrepreneurial Event Model (Shapero and Sokol, 1982); and the Davidsson Model (Davidsson, 1995), which have been proved to have little difference in terms of the approaches taken by various kinds of models (Krueger, Reilly, and Carsrud 2000), two of them stand out and guide this study: Ajzen's (1991) Theory of Planned Behavior (TPB) and Shapero and Sokol's (1982) Model of Entrepreneurial Event (SEE). Although these models vary in terms of their underlying concepts, they suggest similar interpretations of entrepreneurship intentions (Krueger, Reilly, and Carsrud, 2000).

Shapero (1975) argued that the entrepreneurial event, in other words, initiating entrepreneurial behavior, depends on the existence of a salient, personally credible opportunity, which, in turn, is contingent on perceptions of desirability and feasibility.

Figure 1 illustrates Shapero and Sokol's (1982) Model of Entrepreneurial Event (SEE). According to Shapero's (1975) definition, perceived desirability is both the personal and social attractiveness of starting a business, and perceived feasibility, both personal and social, refers to the degree to which a person feels capable of initiating a business. According to Krueger (1993), perceived desirability in the SEE model refers to "the degree to which one finds the prospects of starting a business to be attractive; in essence, it reflects one's affection toward entrepreneurship." Perceived feasibility is "the degree to which one believes that he or she is personally capable of starting a business" (Krueger, 1993). There is strong empirical support for the impact of perceived desirability on entrepreneurial intention (Summers, 2000).

Intention refers to the degree to which people show their motivation and willingness to execute the desired behavior, and intention is the best predictor of planned behavior (Bagozzi, Baumgartner, and Yi 1989). Since creating a new business involves considerable planning, the TPB model, as illustrated in figure 2, proposed by Ajzen, is suitable to use to analyze entrepreneurial

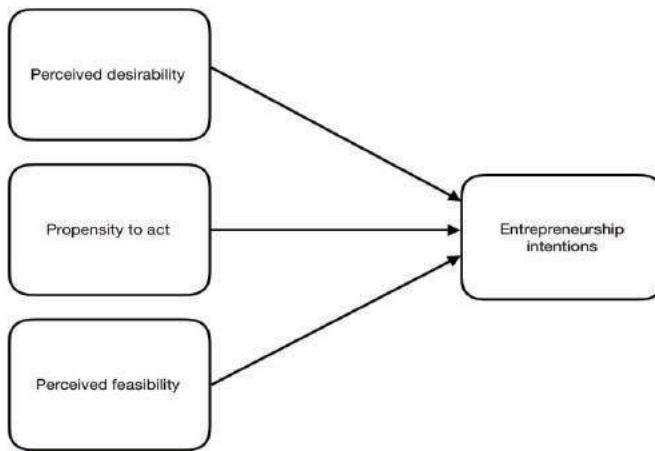


Figure 1.
Shapero and Sokol (1982) Entrepreneurial Event Model

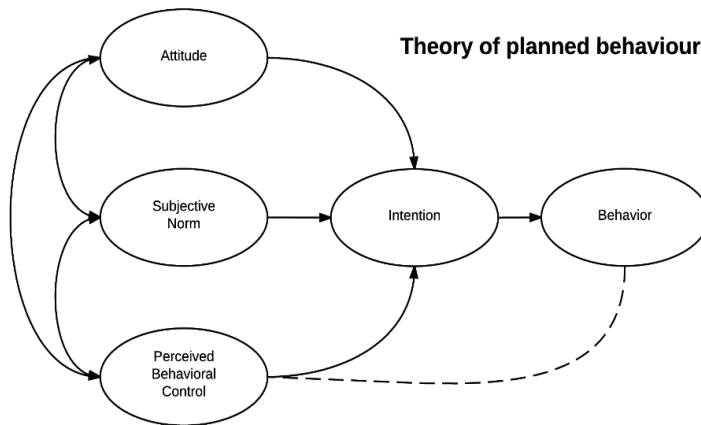


Figure 2.
Ajzen’s Theory of Planned Behavior Model (1991). From Theory of planned behavior, by Robert Orzanna, 2015, https://commons.wikimedia.org/wiki/File:Theory_of_planned_behavior.png.

intention. Ajzen’s Theory of Planned Behavior states that generally speaking, individuals’ intentions and behaviors depend on their attitude toward the act, subjective norm, and perceived behavioral control. The attitude toward the act indicates individuals’ assessment of the personal desirability of creating a new business (Ajzen, 1991). Subjective norm reflects individuals’ perceptions of what important people in their lives think about business creation (Ajzen, 1991). Perceived behavioral control shows individuals’ perception of their ability to initiate a new business successfully (Ajzen, 1991).

Interestingly, these two models are highly similar. Also, “the fact that two scholars in two different academic areas produced highly similar models attests to the value of entrepreneurship intention models” (Saeed et al., 2018). Krueger, Reilly, and Carsrud (2000) tested both Ajzen’s Theory of Planned Behavior Model and Shapero’s Entrepreneurial Event Model and indicated that the attitude and subjective norm in the TPB model are conceptually related to perceived desirability in the SEE, while perceived behavioral control in the TPB corresponds with perceived feasibility in the SEE model.

Thus, in essence, perceived desirability and perceived feasibility are the two main factors influencing entrepreneurial motivations.

Perceived Feasibility. Given that the perception that a new business venture is feasible is a predictor of the intention to launch it, then it is crucial to examine the key indicator of perceived feasibility: entrepreneurship self-efficacy (ESE), the academic term for the belief that one can execute a target behavior (Saeed et al., 2018). This is based on individuals’ self-perceptions of their skills and abilities (Bandura, 1986). In the field of entrepreneurship, ESE has been proved to be a critical indicator of EI (Chen, Greene, and Crick, 1998; Krueger, Reilly, and Carsrud, 2000). Boyd and Vozikis (1994) defined ESE as “an important explanatory variable in determining both the strength of entrepreneurship intentions and the likelihood that those intentions will result in entrepreneurial actions.” Similarly, Krueger and Brazeal (1994) proposed that ESE constitutes one of the key prerequisites for the potential entrepreneur. Since ESE is the same as perceived feasibility, therefore, this study hypothesizes that:

H1: Perceived feasibility positively influences entrepreneurship intentions.

Perceived Desirability. The success of entrepreneurial activity depends upon the attitudes, interests and values of the individuals who are likely to form a new venture (Bird 1988). Hence, the reasons that these potential entrepreneurs have for starting a business venture should have a significant influence on whether they would actually engage in entrepreneurial activity, that is, their EI (Ajzen 1991; Kolvereid 1996; Krueger & Brazeal, 1994; Krueger & Carsrud, 1993). In the Theory of Planned Behavior Model, these reasons are individuals’ attitudes toward self-employment, and in the SEE framework, they can be seen as perceived desirability factors leading to the formation of EI. Thus, this study hypothesizes that:

H2: Perceived desirability positively influences entrepreneurship intentions.

Global Entrepreneurship Monitor. According to the 2001 Global Entrepreneurship Monitor (GEM), there are two types of entrepreneurs in their national surveys—opportunity and necessity entrepreneurs (Reynolds et al., 2002). The difference between these two types of entrepreneurs is that opportunity entrepreneurs decide to set up a business, in some cases by giving up their positions as paid employees, while, on the other hand, a necessity entrepreneur chooses entrepreneurship because no other, or better, external sources of income are readily available (Figueroa-Armijos & Johnson, 2013).

According to the GEM 2018/2019 Global Report, the opportunity-motivation index, which refers to the degree to which entrepreneurship is perceived as a motive for more income or greater independence, is high in high-income countries like the United States and low in low- or middle-income countries like China. Low-income countries provide fewer alternatives, hence their lower opportunity-motivation index. According to Bosma and Kelley (2019), “in this report, the context for entrepreneurship in the United States signals high environmental support for this activity with its entrepreneurial culture, the availability of finance, and advanced legal, commercial and physical infrastructure” (Bosma & Kelley, 2019). On the other hand, the GEM 2018/2019 Global Report also shows that entrepreneurial activity (both early-stage and in the established phase) has diminished over time in China. Bosma and Kelley also argued that “few respondents to the Adult Population Survey (17%) believe it is easy to start a business in China. While only 35% think there are opportunities for starting a business, fewer believe they have the capabilities to do so (24%)” (Bosma & Kelley, 2019).

In particular, according to the GEM 2017 United States Report, which GEM specially created, “among Americans, 64% believe there are good opportunities for starting a business near where they live, the highest level reported since GEM’s first survey in 1999” and “perceived capability among the adult population age 18–64 in the United States is higher than the average of the 23 innovation-driven economies”, which means that perceived feasibility in the United States is among the highest in the world (Lange et al., 2018). As for perceived desirability, the GEM 2017 United States Report suggested that “among Americans, 63% believe that entrepreneurship is a good career choice, which is greater than the average of the innovation-driven economies”, which means higher perceived desirability for Americans (Lange et al., 2018).

According to the GEM 2018/2019 Global Report, as of 2018, the U.S. economy had experienced the strongest recovery among all the OECD countries since the 2008–2010 Global Financial Crisis and had enjoyed one of its longest boom cycles since World War II. Strong and robust economy-wide indices in the last two years, an over-two-percent growth rate, below-two-percent

inflation, and high consumer confidence, may explain the extremely high perceived opportunities (rank 5 out of 49).

Although GEM does not create an individual report particularly for entrepreneurship in China as it does for the United States, the GEM 2018/2019 Global Report does provide some insights into the evolution of entrepreneurship in China over the last 20 years, during which China has experienced uniquely tremendous economic growth. There are various explanations for this phenomenon. According to the GEM 2018/2019 Report, this growth can be attributed to a dual policy of government control and opening up to the international market. Recent years show stable growth that is normalizing but still high at over six percent GDP per capita growth (Bosma & Kelley, 2019). However, one has to keep in mind that a lack of transparency has led experts to be suspicious of the GDP reported by the Chinese government: many experts have maintained that the reality was not as good as the reported data and could be worse to a very large extent. Regarding entrepreneurship in China, entrepreneurial activity has diminished over time, as illustrated in figure 3. The GEM 2018/2019 Report stated that “this can probably be associated with the increased scale that many companies operate with, providing many job opportunities, likely a natural consequence of sustained economic growth” (Bosma & Kelley, 2019).

Additionally, according to the Adult Population Survey, only 17% of respondents believe it is easy to start a business in China (Bosma & Kelley, 2019). While only 35% think there are opportunities for starting a business, even fewer believe they are capable of doing so (24%) (Bosma & Kelley, 2019). Strong physical infrastructure, free and open internal markets, and a culture that supports the entrepreneurship of China have led to its high-level infrastructure (Bosma & Kelley, 2019). According to GEM data, entrepreneurial employee activity rates are especially low in China, which suggests that enhancing innovative behavior among employees may be a possible next focus (Bosma & Kelley, 2019). Entrepreneurship can be a key means of addressing some of the significant challenges China faces, such as inequality, pollution, and health, and improving the healthy economy and educated workforce (Bosma & Kelley, 2019).

The GEM 2018/2019 Global Report regarding entrepreneurship in China includes several key conclusions. 1) According to the Chinese GEM results in 2018, “young people between the age of 25 and 34 are the most active group of entrepreneurs, and the majority of them are opportunity-driven” (Bosma & Kelley, 2019) 2) Most entrepreneurs choose to start their business ventures in the service sector of either wholesale or retail clients. 3) Over the past 15 years, both the proportion of highly educated entrepreneurs and the number of high-income people starting business ventures have increased,

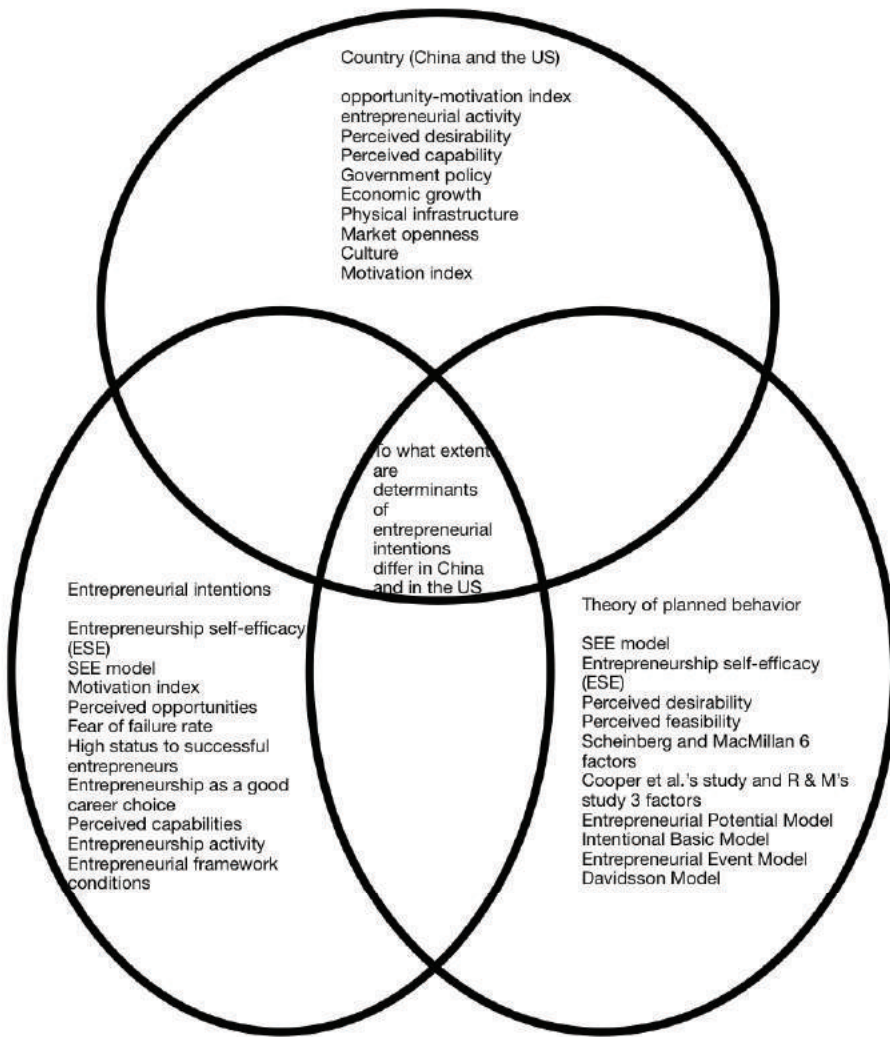


Figure 3.
Research Question and Key Research Domains

while the proportion of under-educated entrepreneurs in China has gradually decreased. 4) “Although the failure rate for entrepreneurs in China has declined, recognition of entrepreneurial abilities also decreased, while fear of failure rate has gradually increased” (Bosma & Kelley, 2019). 5) “Over the past 15 years, the quality of China’s entrepreneurial activities has improved, but there is still a gap compared with the developed countries of the G20 economies” (Bosma & Kelley, 2019). 6) China has high-level physical infrastructure, market openness, and cultural and social norms, but the business

environment, R&D transfer, and education and training still need to improve (Bosma & Kelley, 2019).

Based on data provided by the GEM 2018/2019 Global Report, the global rankings of perceived opportunities, perceived capabilities, and motivational indices are 5, 13, and 5 for the United States and 35, 48, and 44 for China, indicating that people in the United States generally perceive more opportunities, regard themselves as more capable, and are more motivated to be entrepreneurs than people in China (Bosma & Kelley, 2019). In the GEM Global Reports for previous years, the United States shows much higher rankings than China does in these three indicators (Bosma & Kelley, 2019).

In the face of the huge difference between China and the US, it is worth exploring further the reasons behind this tremendous disparity based on the theoretical models discussed before and data provided by the Global Entrepreneurship Monitor.

3. Methodology

This study aims to compare the determinants of entrepreneurial intentions in China and the United States, and the data provided by the Global Entrepreneurship Monitor is complete from 2002, so the research question is: “To what extent do determinants of entrepreneurial intentions differ in China and the United States in the past 18 years?”

Here are the areas of literature I studied for this research project: entrepreneurial intentions, perceived feasibility, perceived desirability, relationship between entrepreneurial intentions and physical infrastructure, market openness, and culture, Chinese culture, American culture, Theory of Planned Behavior model, Shapero and Sokol Entrepreneurial Event Model, Entrepreneurial Potential Model, Intentional Basic Model, Davidsson Model, entrepreneurs’ motivations, entrepreneurship self-efficacy, determinants of entrepreneurial intentions, entrepreneurship activity in the US, and entrepreneurship activity in China.

According to Google Scholar’s ranking, *Entrepreneurship Theory and Practice*, *Journal of Business Venturing*, *Small Business Economics*, and *Technovation* are the second, third, fourth, and seventh top publications respectively under the categorization of Entrepreneurship & Innovation. This research cited four articles from *Entrepreneurship Theory and Practice*, three articles from *Journal of Business Venturing*, one from *Small Business Economics*, and one from *Technovation*. So, this essay’s validity and credibility are thoroughly evaluated.

This is a quantitative study that uses a correlational design. It’s the appropriate method because this study aims to explore the correlation between

entrepreneurial intention and its determinants and compare the results between the two countries.

Sample and Procedure

This research project into entrepreneurial motivations in the United States and China adopts secondary research as the major sources of results. To ensure the validity of information, the major source of data is provided by the Global Entrepreneurship Monitor, which is the world's foremost study of entrepreneurship.

Through a vast, centrally coordinated, internationally executed data collection effort, GEM is able to provide high quality information, comprehensive reports and interesting stories, which greatly enhance the understanding of the entrepreneurial phenomenon. GEM is a trusted resource on entrepreneurship for key international organizations such as the United Nations, World Economic Forum, World Bank, and the Organization for Economic Co-operation and Development (OECD), providing custom datasets, special reports and expert opinion (Global Entrepreneurship Monitor).

The data used for the GEM is collected from two large surveys, the Adult Population Survey (APS) and the National Expert Survey (NES). The APS surveys at least 2000 adults of each country covered by the GEM and covers the entrepreneurial aspirations of the country's population. The NES surveys a group of business and academic experts in each country with a broad range of specialties for concrete measures of the country's institutional factors. Overall, GEM provides 20 years of data, conducts 200,000+ interviews a year, covers 100+ economies, incorporates 500+ specialists in entrepreneurship research, 300+ academic and research institutions, and 200+ funding institutions. 20 years on, GEM is the richest resource of information on entrepreneurship study, publishing a wide range of global, national and "special topic" reports annually (Global Entrepreneurship Monitor).

The large sample size and authority of experts surveyed demonstrate the high reliability of data provided by GEM. The concern is the limited range of key data since the majority of numerical data and graphs are from GEM. However, GEM is the only organization that provides comprehensive, extensive, and reliable data regarding entrepreneurship. Its reliability, complemented by other secondary sources of data and a critical analysis of the data, may compensate for the limited range of key data used in this research. Thus, the study will also incorporate information from the internet such as online business journals, magazine articles, government reports, and blog posts (choosing sources that are known to be reliable).

GEM provides data on Entrepreneurial Behavior and Attitudes, including 1) Perceived Opportunities, 2) Perceived Capabilities, 3) Fear Of Failure Rate, 4) Entrepreneurial Intentions, 5) Total Early-Stage Entrepreneurial Activity (TEA), 6) Established Business Ownership, 7) Entrepreneurial Employee Activity, 8) Motivational Index, 9) Female/Male TEA, 10) Female/Male Opportunity-Driven TEA, 11) High Job Creation Expectation, 12) Innovation, 13) Business Services Sector, 14) High Status To Successful Entrepreneurs, 15) Entrepreneurship As A Good Career Choice (GEM Global Entrepreneurship Monitor). Some of these categories can be utilized to fit into the three subsections mentioned before.

This study chose eight indicators from the 15 and grouped them into three categories.

Measurement Variables

As mentioned before, Ajzen's (1991) Theory of Planned Behavior (TPB) and Shapero and Sokol's (1982) Model of Entrepreneurial Event (SEE) are similar, except that the element of propensity to act in the SEE model does not correlate with TPB directly. Perceived desirability and perceived feasibility in the SEE model cover all three aspects of the TPB model. To avoid the situation where one subsection has too much content, this research uses the **Theory of Planned Behavior Model** instead of the SEE model to divide all information into three subcategories instead of two. Thus, the three subcategories in the analysis part are the **attitude toward the act (attitude)**, **subjective norm**, and **perceived behavioral control**. The attitude toward the act indicates individuals' assessment of the personal desirability of creating a new business (Ajzen, 1991). Subjective norm reflects individuals' perceptions of what important people in their lives think about business creation (Ajzen, 1991). Perceived behavioral control shows individuals' perception of their ability to initiate a new business successfully (Ajzen, 1991).

Of these areas, Entrepreneurial Intentions and Total Early-Stage Entrepreneurial Activity (TEA) not only serve as the background information for the analysis but also shed insight on the relationship between intentions and TEA by comparing these two figures. In other words, "for the number of people currently starting or running a new business, how many others intend to take these steps in the next three years" (since intentions are assessed among non-entrepreneurs in the GEM reports) (Bosma & Kelley, 2019). These two indicators do not belong to any of the three subcategories, but they serve as the basic introduction, or the background information, of the analysis because they directly indicate entrepreneurship and entrepreneurship intentions.

The motivational index, perceived opportunities rate, and fear of failure rate indicate attitude toward the act. The motivational index is defined as the “percentage of those involved in TEA that is improvement-driven opportunity motivated, divided by the percentage of TEA that is necessity-motivated” (Bosma & Kelley, 2019). A higher motivation index means more people choose to become entrepreneurs because they see opportunities to improve their lives (improvement-driven opportunity motivated) instead of being forced to start a business to make a living (necessity motivated). Thus, a higher motivation index means more entrepreneurship activities are more desirable to people because they are willing to undertake them for improvement. So, motivation index should be an indicator of attitude. Perceived opportunities rate refers to the “percentage of 18–64 population (individuals involved in any stage of entrepreneurial activity excluded) who see good opportunities to start a firm in the area where they live” (Bosma & Kelley, 2019). Those who “see good opportunities to start a firm in the area where they live” means that they regard entrepreneurship as desirable, so perceived opportunities should be an indicator of attitude. Fear of failure rate means the “percentage of 18–64 population (individuals involved in any stage of entrepreneurial activity excluded) who indicate that fear of failure would prevent them from setting up a business” (Bosma & Kelley, 2019). The more one fears failure, the less entrepreneurship seems desirable, so the less likely he or she is going to take risks and become an entrepreneur, so the fear of failure rate is also an indicator of attitude.

The perceived Capabilities rate indicates perceived behavioral control. The perceived capabilities rate measures the “percentage of 18–64 population (individuals involved in any stage of entrepreneurial activity excluded) who believe they have the required skills and knowledge to start a business” (Bosma & Kelley, 2019). Those who believe “they have the required skills and knowledge to start a business” literally perceive themselves as capable, having the ability to “initiate a new business successfully” (Bosma & Kelley, 2019). Thus, perceived capabilities rate fits into the perceived behavioral control subsection.

High status to successful entrepreneurs rate and entrepreneurship as a good career choice rate indicates subjective norm since these two figures measure societal attitudes toward entrepreneurship. High status to successful entrepreneurs rate is the “percentage of 18–64 population who agree with the statement that in their country, successful entrepreneurs receive high status” (Bosma & Kelley, 2019). When most successful entrepreneurs receive high status, most people will recommend entrepreneurship as a desirable path for their close friends, family members, etc. Thus, this will enhance individuals’ perceptions of what important people in their lives think about

entrepreneurship. So, high status to successful entrepreneurs is an indicator of the subjective norm. Entrepreneurship as a good career choice rate refers to the “percentage of 18–64 population who agree with the statement that in their country, most people consider starting a business as a desirable career choice” (Bosma & Kelley, 2019). Other people’s, including important ones’, perceptions about the desirability of entrepreneurship will influence one’s perception of business creation, so entrepreneurship as a good career choice is an indicator of the subjective norm.

Thus, the proposed research framework is illustrated in figure 4.

4. Results

Background

From figure 5 and figure 6, the consistency between entrepreneurial intentions (EI) and TEA is clear. The correlation coefficient between these two variables in China is 0.54 and in the United States is 0.80. Furthermore,

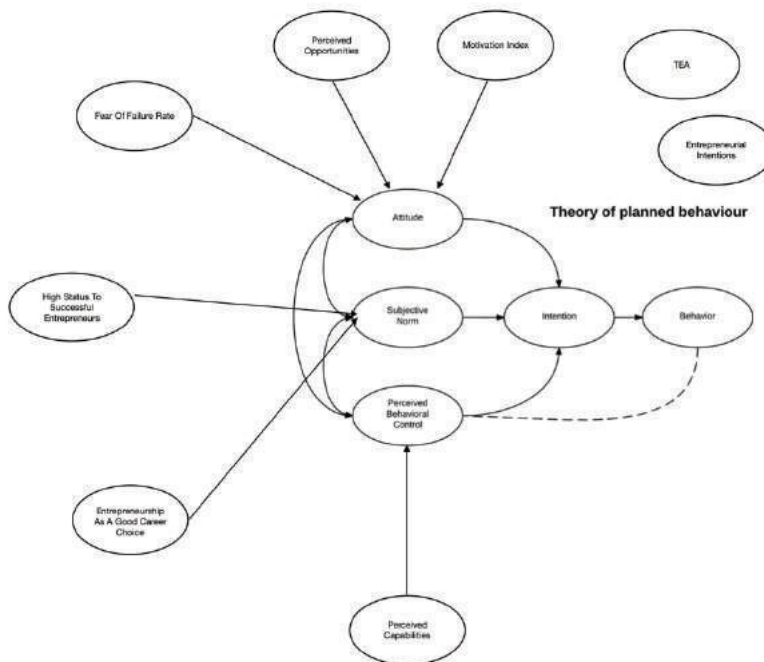


Figure 4.
Proposed Research Framework

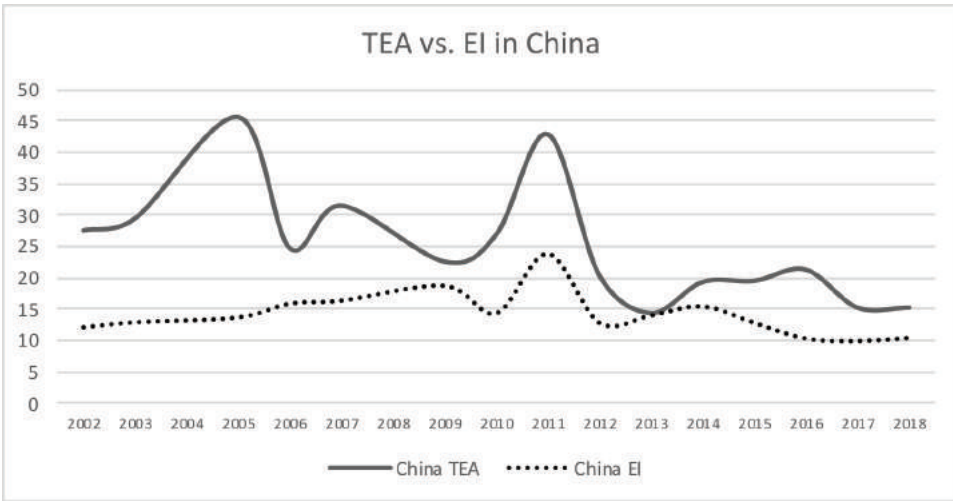


Figure 5.

TEA vs. EI in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

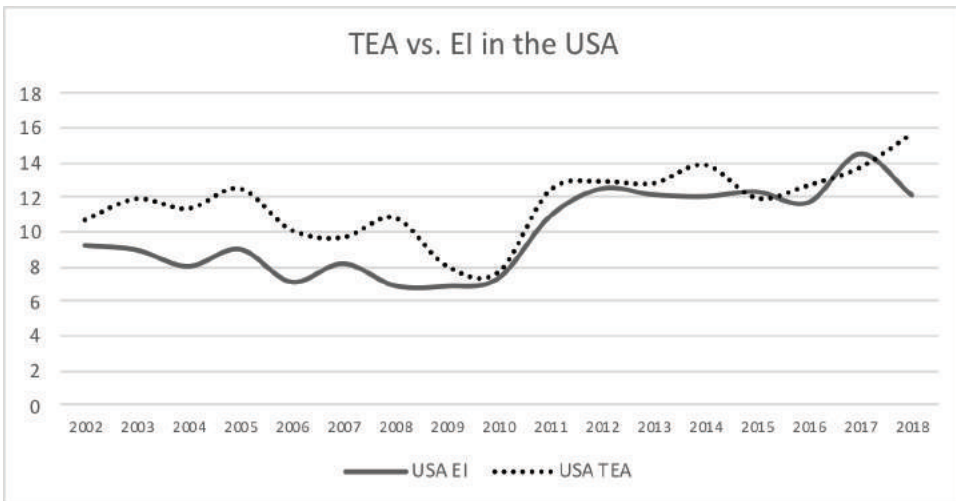


Figure 6.

TEA vs. EI in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

from 2010 to 2018, this figure in China skyrocketed to 0.88, suggesting a strong, positive correlation between these two indicators in both countries. This further proves the significance of EI in entrepreneurial activities that can promote economic growth. Thus, exploring the drivers behind EI is crucial for the economy.

When comparing EI in China and in the United States, as illustrated in figure 7, we can see that 1) EI in China are consistently higher than in the

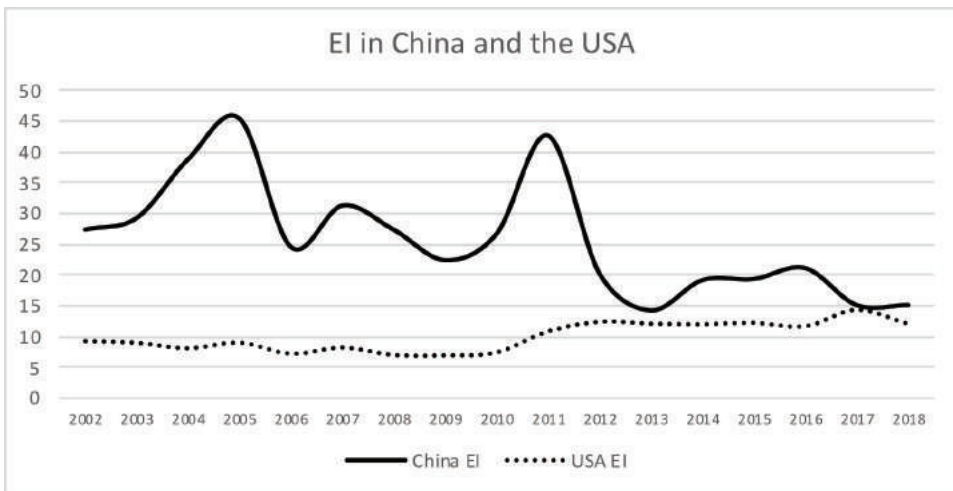


Figure 7.

EI in China vs. in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

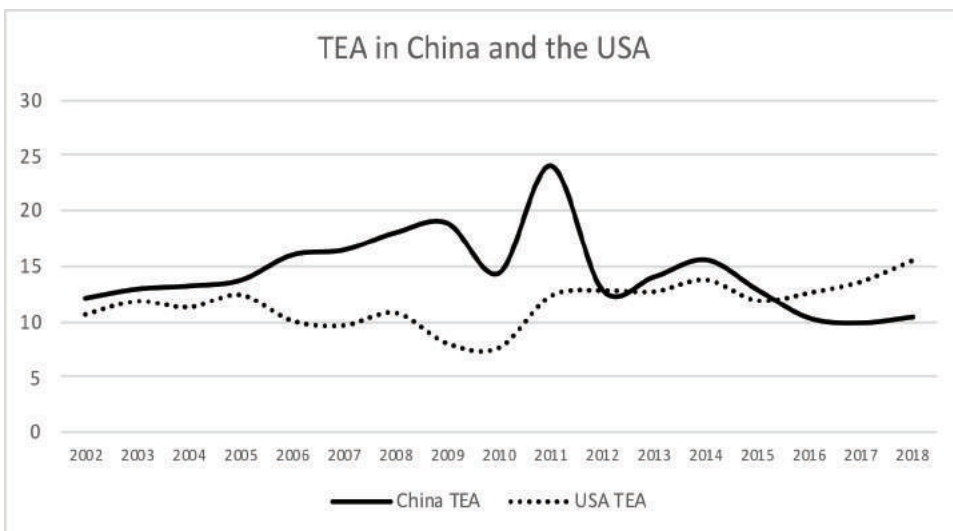


Figure 8.

TEA in China vs. in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

United States; 2) EI in China are volatile, but are becoming stable, especially from 2013, while EI in the United States are consistently stable from 2002 to 2018; 3) EI in both countries became closer in the recent 5 years.

In figure 8, we can see that in 2011, TEA in China experienced a rapid increase that was followed by a rapid decrease. Then, in 2014, there was a similar “bump”, but not as large as the one in 2011. Furthermore, according to

figure 9, TEA in the United States reached the minimum level in 2009–2010, when the huge negative effect of 2008 Global Financial Crisis destroyed millions of jobs in the US, especially small businesses that did not have enough capital to survive this economic disaster. Thus, that the minimum level of TEA in the United States was reached in this period is understandable.

Attitude

Motivational Index: In accordance with the GEM 2018/2019 Report, “percentage of those involved in TEA that is improvement-driven opportunity motivated, divided by the percentage of TEA that is necessity-motivated” (Bosma & Kelley, 2019), or

$$\frac{\% \text{ improvement - driven opportunity motivated}}{\% \text{ necessity - motivated}}$$

According to the GEM 2018/2019 Global Report, improvement-driven opportunity (IDO) motive refers to “the proportion of entrepreneurs who are opportunity-motivated and improvement-driven, in terms of seeking higher income or greater independence.” It accounts for an average of 42% of entrepreneurs among the middle-income economies, which include China, and 51% in the high-income economies, which include the United States (Bosma & Kelley, 2019). IDO is the numerator of the motivational index.



Figure 9. The motivational index in China vs. in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

The GEM 2018/2019 Global Report also suggested that “the level of necessity motive drops as economic development level increases.” As the necessity motive is the denominator of the motivational index, when the economy grows, the motivational index should also become higher.

From figure 9, we can see the motivational index in China has remained stable (but consistently lower than in the US) for the last 8 years. However, according to World Bank national accounts data and OECD National Accounts data files, as illustrated in figure 10, China’s GDP approximately doubled during this period. So, the motivation index in China should become larger along with the GDP growth, but it has remained stable. Thus, IDO motive in China, or the numerator of the motivational index, must have decreased to a large extent.

According to World Bank’s data, the U.S. GDP also shows a consistent increase, growing from about 15 trillion dollars in 2010 to about 20 trillion dollars in 2017 (a roughly 33% increase, much lower than the growth rate of the motivational index, indicating that the U.S. IDO motive also increases to a large extent). From figure 10 we can also see that the U.S. GDP is much higher than that of China. This may explain why the motivational index of the United States is much higher than that of China. A higher-level economy means more IDO and less necessity-driven opportunities, and thus the higher motivational index.

From figure 11, we can see that in China, from 2013 to 2018, both the motivational index and EI stayed relatively stable. The correlational

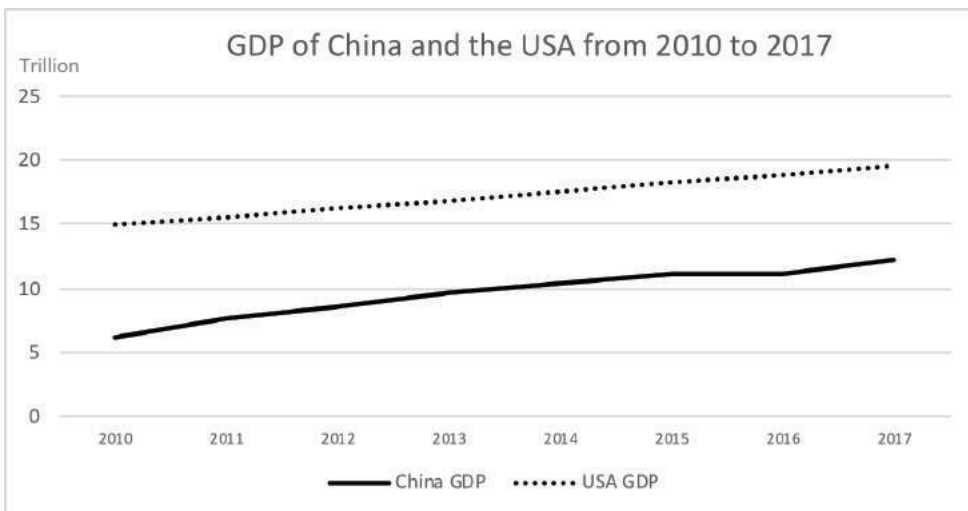


Figure 10.

GDP of China and the United States from 2010 to 2017. From China GDP Trend, by World Bank, <https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=CN>

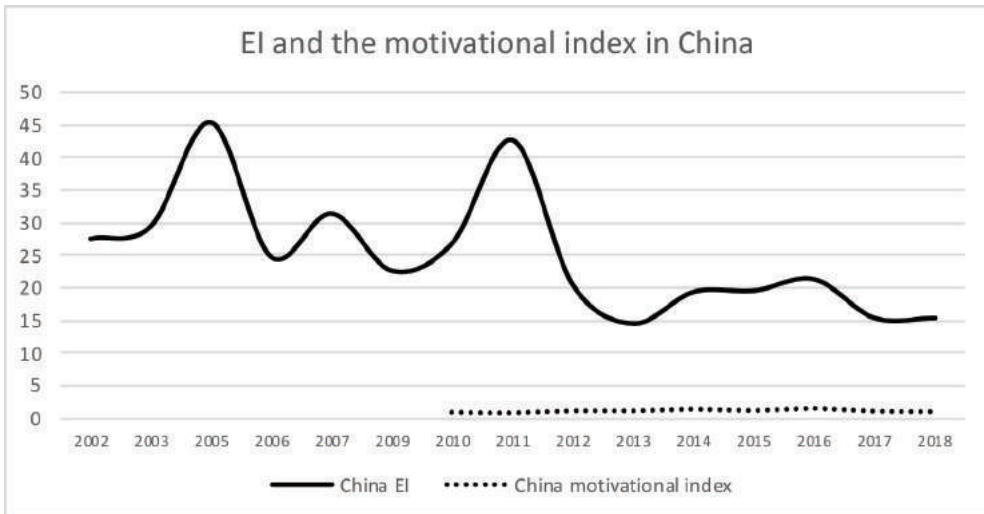


Figure 11.

EI and the motivational index in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

coefficient between them during this time is up to 0.90, indicating a strong positive correlation. However, from 2010–2012, EI in China experienced a huge and rapid increase and decrease (a “bump”), but the motivation index remained stable, which means that both opportunity-driven and necessity-driven entrepreneurs experienced the “bump” in EI. This suggests the reason for that “bump” is not related to the type of entrepreneurs, but more likely due to the wider economic reasons. It is worth mentioning that EI and the motivational index in China from 2010 to 2012 had a perfect negative correlation (-1.00). Further, this is likely to relate to the Chinese government policies regarding encouraging university graduates to start up their businesses during that period. Overall, the correlation between EI and the motivational index in China is negative (-0.44).

From figure 12, it seems that EI in the United States grows in alignment with the motivational index. But the correlation coefficient during this time is only 0.49, suggesting a positive, but not strongly positive correlation.

Perceived opportunities rate: “percentage of 18–64 population (individuals involved in any stage of entrepreneurial activity excluded) who see good opportunities to start a firm in the area where they live” (Bosma & Kelley, 2019).

From figure 13 and figure 14, there appears to be a relatively positive correlation between perceived opportunities and EI in both countries, which makes sense because people have to first perceive opportunities before they can have intentions to pursue those opportunities. However, there was an

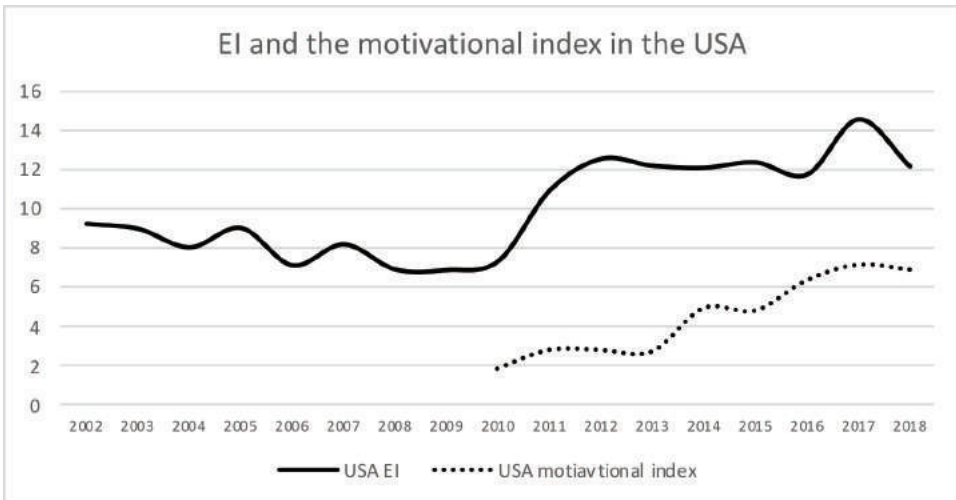


Figure 12.

EI and the motivational index in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

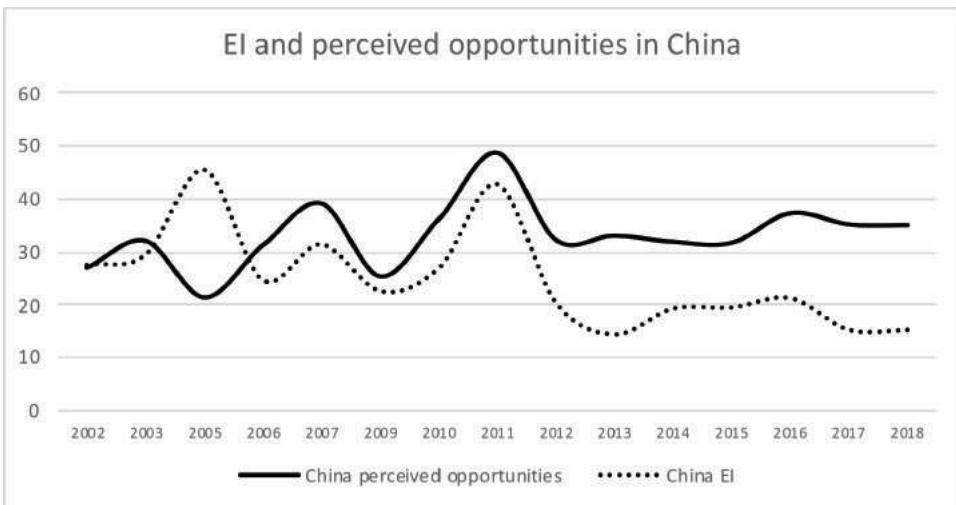


Figure 13.

EI and perceived opportunities in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

extremely strong negative correlation between EI and perceived opportunities in China from 2002 to 2006 (-0.96). The relatively strong positive correlation only starts to appear after 2006 (0.73). Because of the huge difference in terms of the level of correlation before and after 2006, the overall relationship is unclear (0.08). Unlike in China, there was always a strong positive correlation between the two indicators in the United States from 2002 to 2018 (0.83).

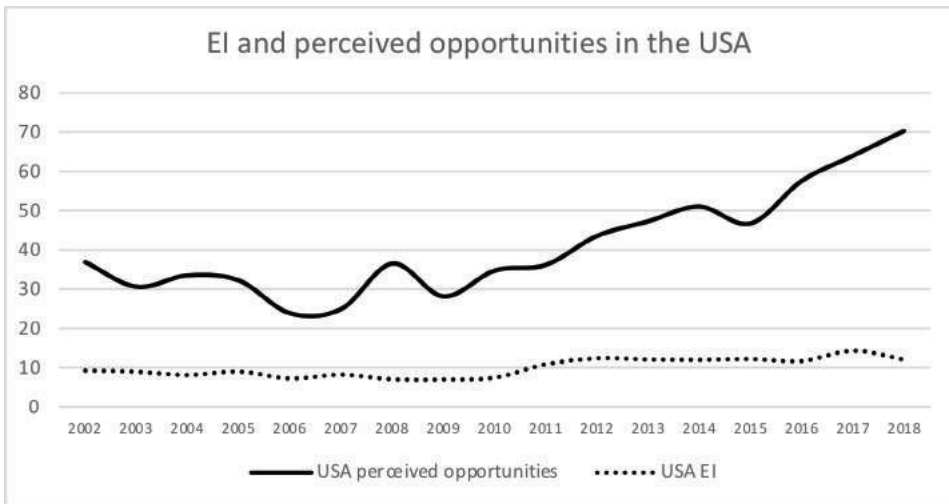


Figure 14.
EI and perceived opportunities in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>



Figure 15.
Perceived opportunities in China and the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

The difference in China and the United States may suggest that in China, many more factors are involved and mingled with each other, so extracting a predictive factor of EI according to the TPB model is harder.

In figure 15, one can see that before 2012, perceived opportunities in the two countries were relatively close to each other; however, since 2012, the U.S. rate went higher than that of China. To some extent, this shows that

the government policies in encouraging college graduates to become entrepreneurs in China were not very effective. The Chinese government should invest more to increase people's perceived opportunities.

Fear of Failure Rate: “percentage of 18–64 population (individuals involved in any stage of entrepreneurial activity excluded) who indicate that fear of failure would prevent them from setting up a business” (Bosma & Kelley, 2019).

Fear is involved in the decision-making process and affects people's cognitive and behavioral responses (Gray, 1971; Damasio 1994). The idea that fear plays a role within the entrepreneurial process accords with the assumption that entrepreneurship is an emotional journey (Baron, 2008).

Figure 16 generally suggests a negative correlation between the fear of failure rate and EI in China (-0.68): when the fear of failure rate is high, EI is low and vice versa. This is especially apparent from 2003 to 2006 (-1.00). This pattern makes sense because the more one fears failure, the less likely he or she is willing to take risks and become an entrepreneur. However, from 2013 to 2018, the correlation is positive (0.45), which is unexpected in terms of the commonsense observation in the last sentence.

Interestingly, as shown in figure 13, the perceived opportunities were also very low in 2005, so was the fear of failure rate, but EI in 2005 was unusually high, which may suggest that the fear of failure rate is a stronger predictor, or indicator, of EI than perceived opportunities. In 2005, although Chinese people did not perceive many opportunities to take advantage of, they were somehow encouraged so that they didn't fear the failure so much and were more willing



Figure 16.

The fear of failure rate and EI in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

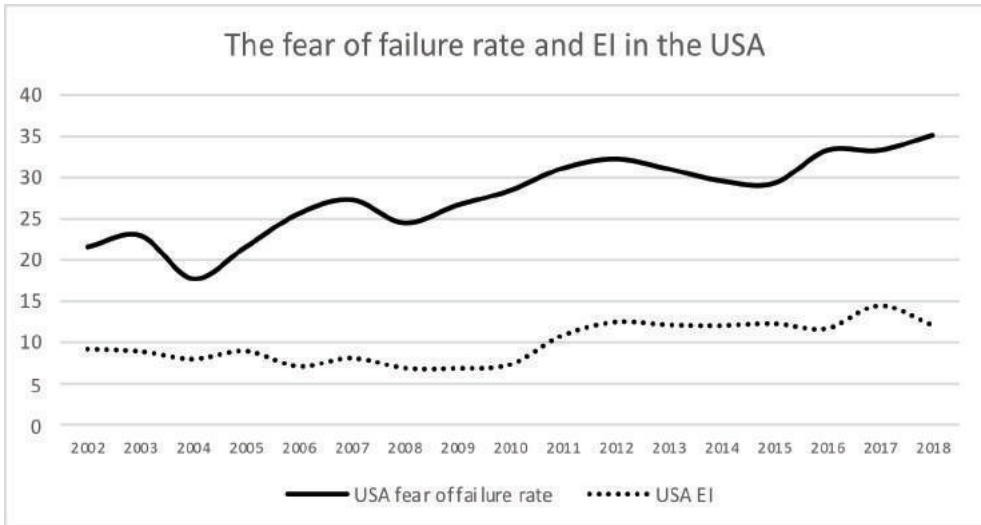


Figure 17.
The fear of failure rate and EI in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

to become entrepreneurs. The reasons for the encouragement are not clear and thus worth exploring in future studies. They may be related to Chinese government policies regarding encouraging entrepreneurship at that time.

Figure 17 shows a relatively positive correlation (slow increase in the last 18 years) between these two indicators in the United States (0.71). However, the expected relationship is negative, and in figure 17, only 2002–2003 and 2016–2018 (-1.00) show (perfectly) negative correlations. Thus, generally speaking, the expected relationship is not the case in the United States.

From figure 18, one can see that generally speaking, fear of failure rates in both countries increase over time. People are less likely to take risks than before; instead, they want stable jobs with less possible benefits or losses.

Subjective norm

High status to successful entrepreneurs rate: “percentage of 18–64 population who agree with the statement that in their country, successful entrepreneurs receive high status” (Bosma & Kelley, 2019).

As shown in figure 19, the high status to successful entrepreneurs rate and EI have a negative correlation (except for 2012–2013 and 2016–2017) in China (-0.46), especially from 2003 to 2006 (-0.99). This negative correlation indicates that although entrepreneurs may be held in high status in China (actually they are held in very high regard in China, with about 70–80% of the respondents agreeing), people may not think entrepreneurship

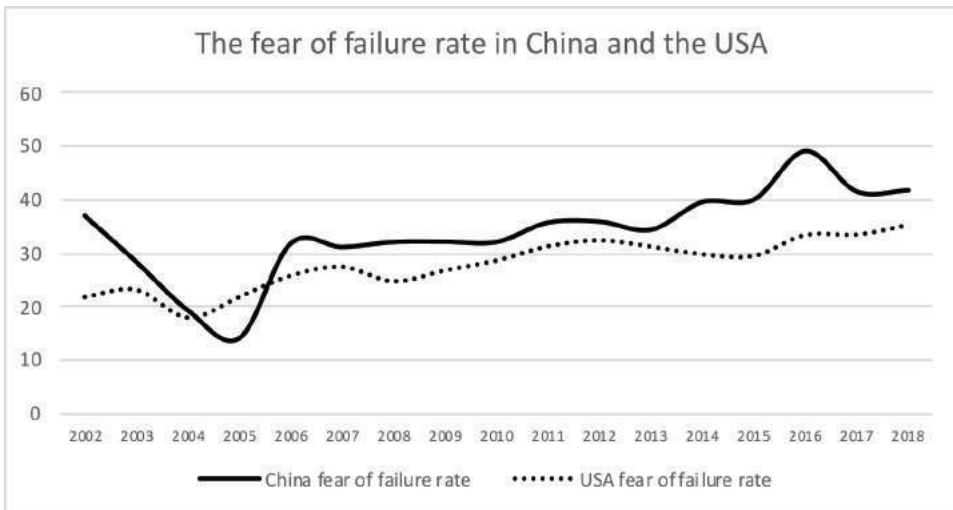


Figure 18.

The fear of failure rate in China and the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

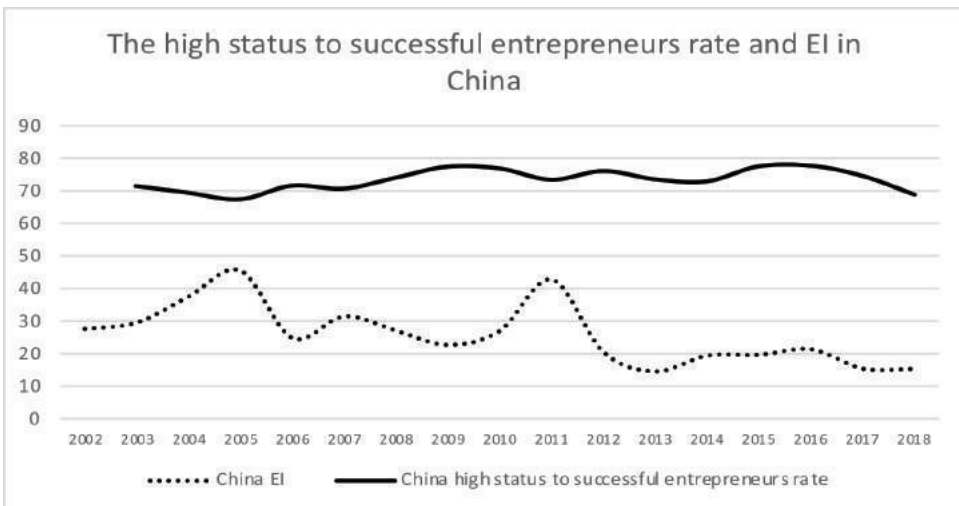


Figure 19.

The high status to successful entrepreneurs rate and EI in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

is something they, or perhaps anyone else they know or are close to, should or can do (Bosma & Kelley, 2019). Again, this shows that people are more willing to take jobs that render stable income at the expense of giving up the chances to earn a lot more money and have higher social status.

In figure 20, one can see that apart from the period 2005–2008, during which the high status to successful entrepreneurs rate in the United States

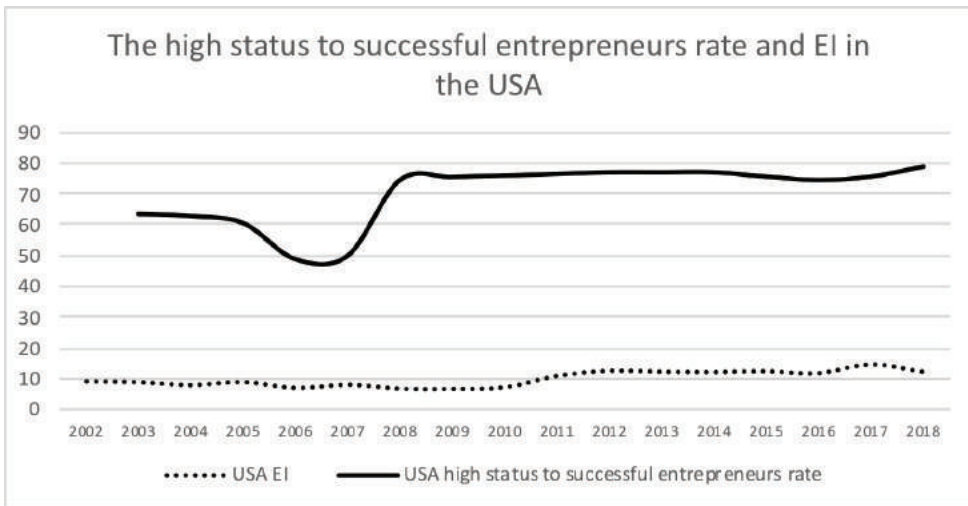


Figure 20.

*The high status to successful entrepreneurs rate and EI in the United States.
From GEM Data, by GEM, <https://www.gemconsortium.org/data>*

fluctuated largely while EI maintained about the same level, EI stays stable, while the high status to successful entrepreneurs rate increases from about 60% before the fluctuation to about 75% after the fluctuation. Although there was an increase, apart from the fluctuation, the periods 2003–2005 and 2008–2018 saw stable patterns for both EI and the high status to successful entrepreneurs rate. However, similar patterns do not suggest a positive correlation. In fact, from 2003 to 2005, the correlation between these two variables was perfectly negative (-1.00). But even so, the overall correlation coefficient is 0.54. This indicates that, in the United States, these two figures are generally in alignment with each other, unlike the situation in China, where a negative correlation occurs.

Figure 21 suggests that before 2008, a larger proportion of Chinese viewed entrepreneurs as of high status. After 2008, a similar proportion (about 70% to 80%) do so in both countries. However, from 2015–2016, the high status to successful entrepreneurs in China started to drop, and this trend may continue into 2019. On the contrary, from 2016, this figure in the United States shows an upward trend, which is also likely to last into 2019.

Entrepreneurship as a good career choice rate: “percentage of 18–64 population who agree with the statement that in their country, most people consider starting a business as a desirable career choice” (Bosma & Kelley, 2019).

Figure 22 is very similar to figure 20, which shows the high status to successful entrepreneurs rate and EI in the United States. There is also an

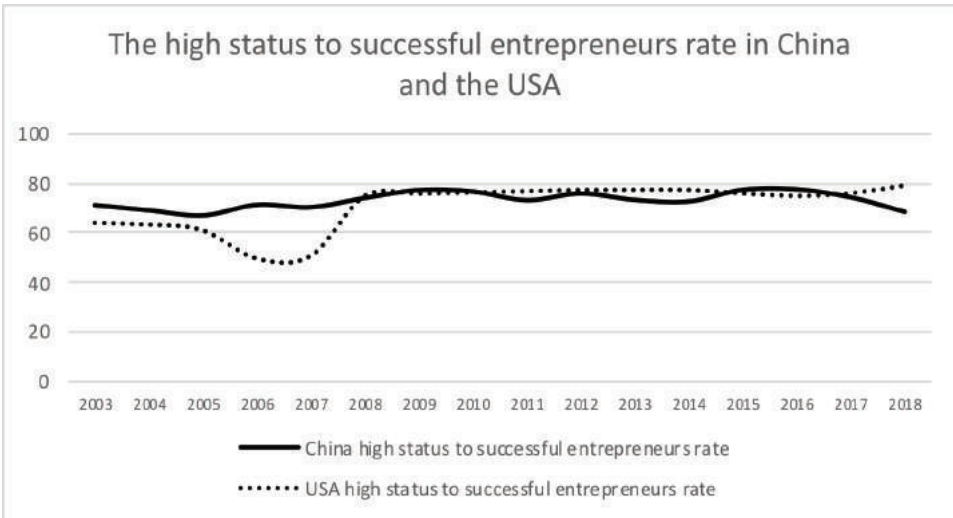


Figure 21.

The high status to successful entrepreneurs rate in China and the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

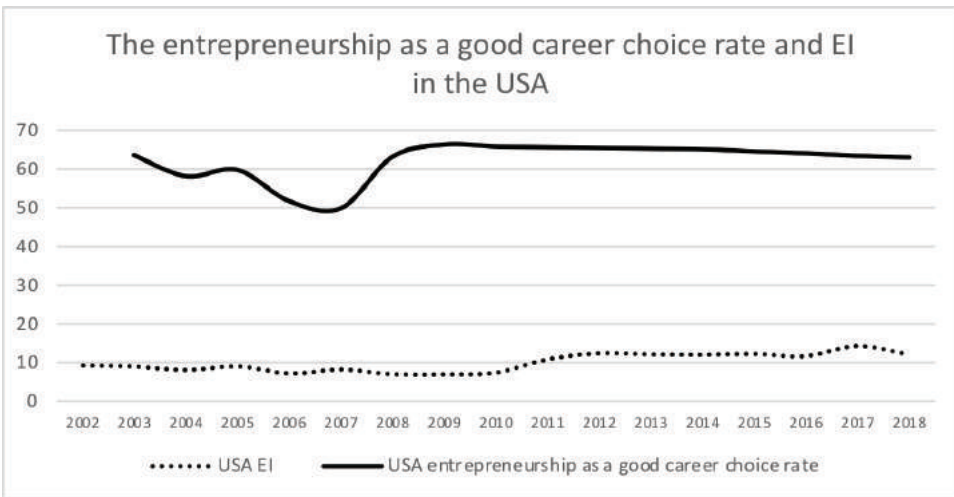


Figure 22.

The entrepreneurship as a good career choice rate and EI in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

overall positive correlation between the entrepreneurship as a good career choice rate and EI in the United States (0.42). However, unlike figure 20, the correlation from 2003 to 2005 was perfectly positive (1.00). This also means that the high status to successful entrepreneurs rate and the entrepreneurship as a good career choice rate from 2003 to 2005 had a perfect negative correlation (-1.00). Thus, according to the TPB model, the entrepreneurship

as a good career choice rate may be a better indicator of EI compared to the high status to successful entrepreneurs rate, at least in the United States.

Overall, the entrepreneurship as a good career choice rate and EI in China have a positive correlation (0.69). As shown in figure 23, there were more fluctuations in terms of the entrepreneurship as a good career choice rate in China compared to that in the United States.

From figure 24, one can see that the entrepreneurship as a good career choice rate and the high status to successful entrepreneurs rate are very similar. These two indicators have an extremely strong positive correlation (0.96), although they had a perfect negative correlation from 2003 to 2005. This indirectly supports the accuracy of the data because societal attitudes should be consistent overall.

The high level of similarity between the entrepreneurship as a good career choice rate and the high status to successful entrepreneurs rate also holds true in China after 2011, as illustrated in figure 25. Before 2011, these two variables in China had a negative relationship (-0.60), which means that the entrepreneurship as a good career choice rate and EI in China have a positive relationship (0.79). After 2011, the correlation coefficient between the entrepreneurship as a good career choice rate and the high status to successful entrepreneurs rate in China went to 0.72, suggesting a relatively strong positive correlation between the two variables.

Another pattern seen in both figure 24 and figure 25 is that, in general, people in both countries are more likely to believe successful entrepreneurs

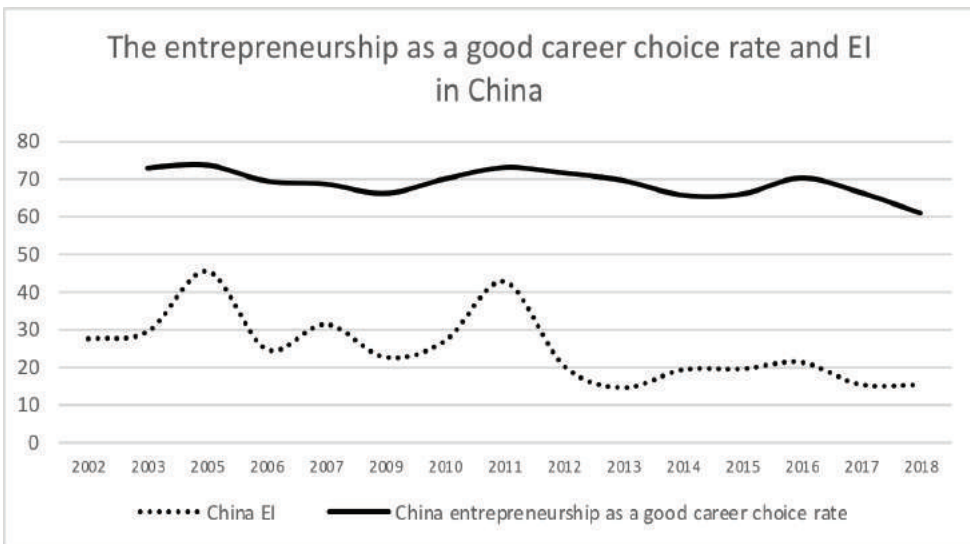


Figure 23.

The entrepreneurship as a good career choice rate and EI in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

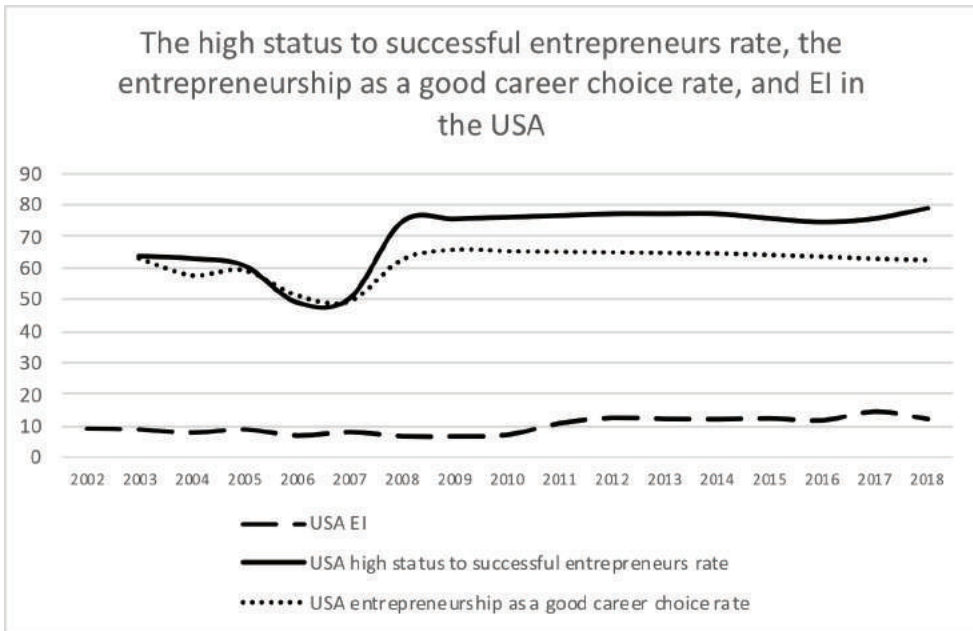


Figure 24.

The high status to successful entrepreneurs rate, the entrepreneurship as a good career choice rate, and EI in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

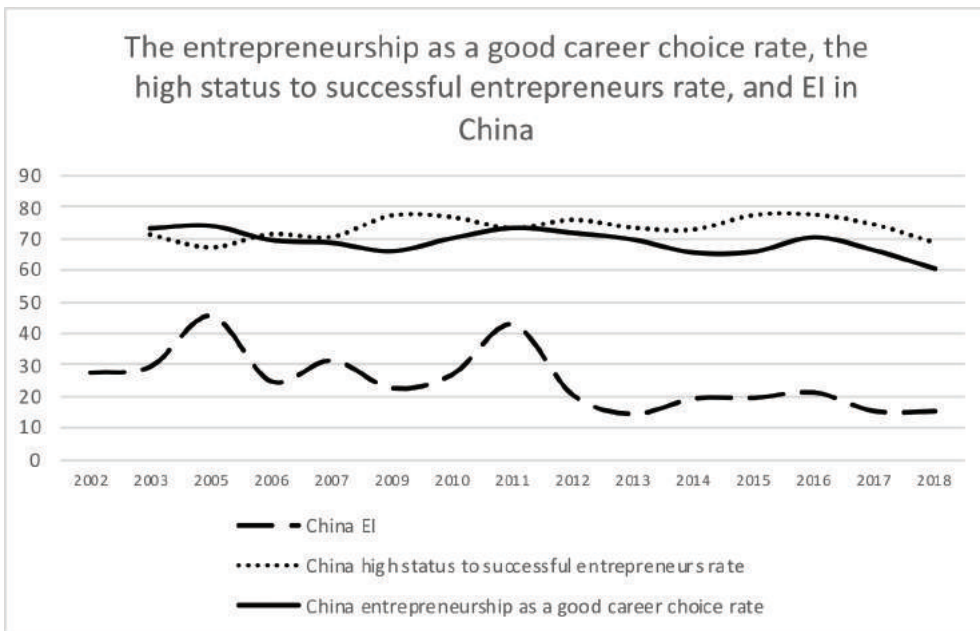


Figure 25.

The entrepreneurship as a good career choice rate, the high status to successful entrepreneurs rate, and EI in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

have high status than to think entrepreneurship is a good career choice, “illustrating how more people hold entrepreneurs in high regard than believe this is something they or others should venture into” (Bosma & Kelley, 2019). According to the GEM 2018/2019 Global Report, like China and the United States, “most European and North American countries show lower levels of attitudes about entrepreneurship as a career choice than about the status of entrepreneurs” (Bosma & Kelley, 2019).

Furthermore, on average, 62% of adults believe entrepreneurship is a good career choice, according to the GEM 2018/2019 Global Report, which is lower than about 70% to 80% in China and the United States (Bosma & Kelley, 2019). This means that the framework conditions of entrepreneurship in China and the United States are better than the world average so that people are more likely to see entrepreneurship as a good career choice. Indeed, according to the GEM 2018/2019 Global Report, most indicators of entrepreneurial framework conditions in the United States and China received above-average ratings by experts.

The U.S. culture and social norms stand out, which makes sense: the entrepreneurial spirit has been deeply rooted throughout US history. China’s physical infrastructure and internal market dynamics stand out. China is famous for huge spending on infrastructure construction in the last decade. Many economists believe that China overspent on infrastructure and there are many useless buildings in cities in China. Also, strong internal market dynamics indicate the huge role the Chinese government plays in the market, affecting prices and the behavior of consumers and producers.

These observations show the differences between the economic institutions in the two countries. The main function of economic institutions is to provide a mechanism for decision-making about what, how, and for whom the society should perform economic activities. China’s central government has a high degree of control over the economic institutions, while in the United States, different economic institutions, like the United States Federal Reserve, the National Bureau of Economic Research, and the Internal Revenue Service, etc., have their own decision-making power. They usually collaborate instead of only following orders from the central government.

Perceived behavioral control

Perceived capabilities rate: “percentage of 18–64 population (individuals involved in any stage of entrepreneurial activity excluded) who believe they have the required skills and knowledge to start a business” (Bosma & Kelley, 2019).

In China, as illustrated in figure 26, EI have a slightly positive relationship with perceived capabilities (0.22). From its peak in 2011, the perceived capabilities rate in China decreased until 2015. It is worth mentioning that in 2014, the Chinese government launched a new policy to promote entrepreneurship and innovation, the mass entrepreneurship and innovation strategy, and planned to optimize its institutional support mechanism and improve financial policies and public services for entrepreneurs. The turn-around in 2015 might be the result of this. However, after 2016, the perceived capabilities rate decreased again until now, which means that the new policy is not very effective.

Again, the interesting pattern in the year 2005 appears: the level of perceived capabilities was low, but EI were high at the time. In fact, from 2003 to 2006, EI and perceived capabilities in China had a perfectly negative correlation (-1.00). This may suggest that the fear of failure rate is not only a better predictor of EI than perceived opportunities but also a better one compared to perceived capabilities, at least in China.

In the United States, there is also a slightly positive relationship between EI and perceived capabilities (0.11) shown in figure 27. But there are also areas where negative correlations occur. For example, from 2003 to 2004, EI increased, while perceived capabilities decreased; from 2006 to 2007, the same thing happened again; then from 2007 to 2008, the pattern reversed as EI decreased while PC increased; from 2010 to 2011, EI increased again, while PC decreased; the negative relationship also occurred from 2016 to

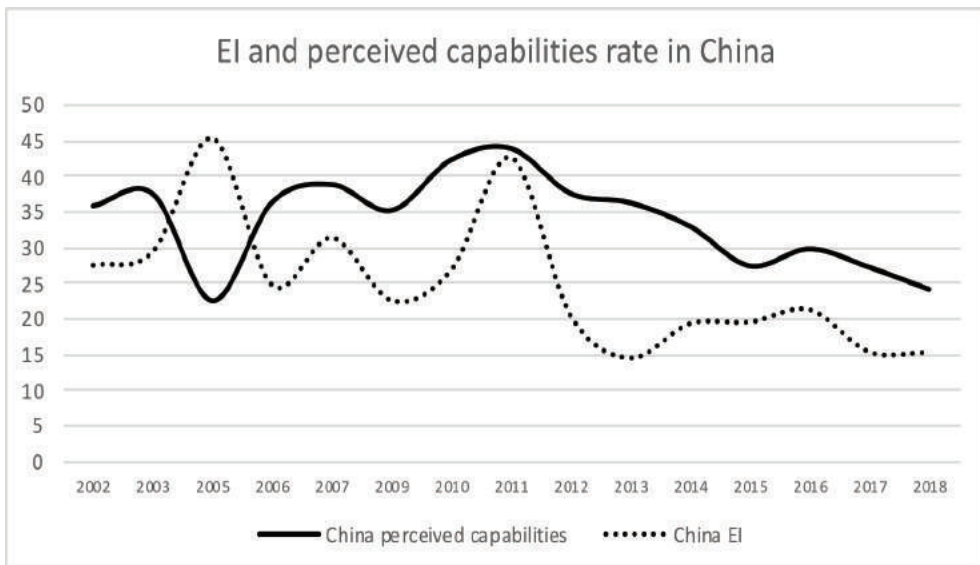


Figure 26.

EI and perceived capabilities rate in China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

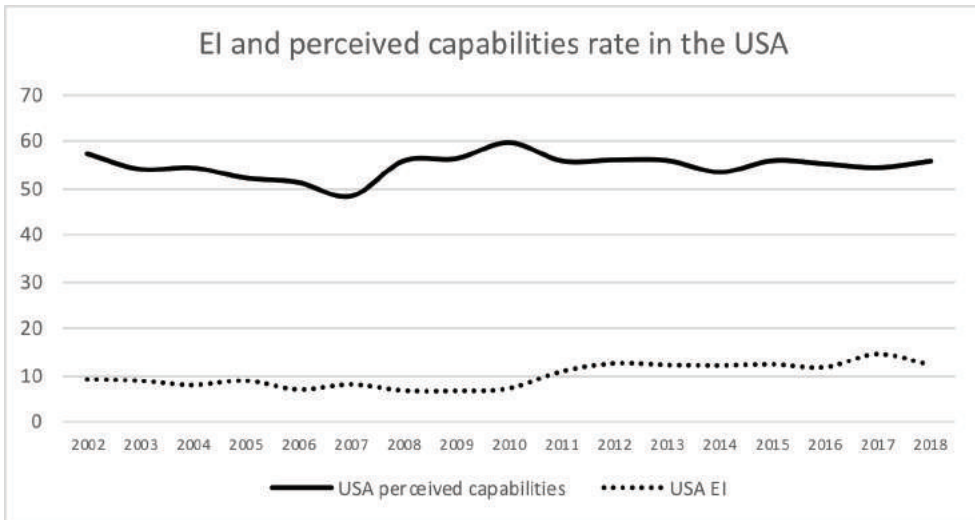


Figure 27.

EI and perceived capabilities rate in the United States. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

2018. However, these were generally only small changes and fluctuations. The two figures, in general, are quite stable, compared to those in China, and even have a slightly positive relationship.

From figure 28, we can see clearly that more Americans than Chinese think they are capable of starting up businesses and becoming entrepreneurs. The cultural differences might play a role here aside from the differences related to entrepreneurship itself. Generally speaking, American parents are more likely to expect their children to be independent, while Asian parents control many aspects of their children's lives (Mei, 2018). Thus, when talking about entrepreneurship, which means one needs to create and run a business by oneself, it makes sense that more independent people are more likely to believe they can do that. Chinese who are used to their parents' help are likely to see themselves as less capable of starting up a new business by themselves.

5. Conclusion

The Chinese have more entrepreneurial intentions than Americans do. The improvement-driven opportunities motive decreased significantly in China while it increased in the United States. Necessity-driven entrepreneurship is more popular in China due to the country's lower level of economic development. In the United States, the motivational index and perceived opportunities have a positive relationship with entrepreneurial intentions.

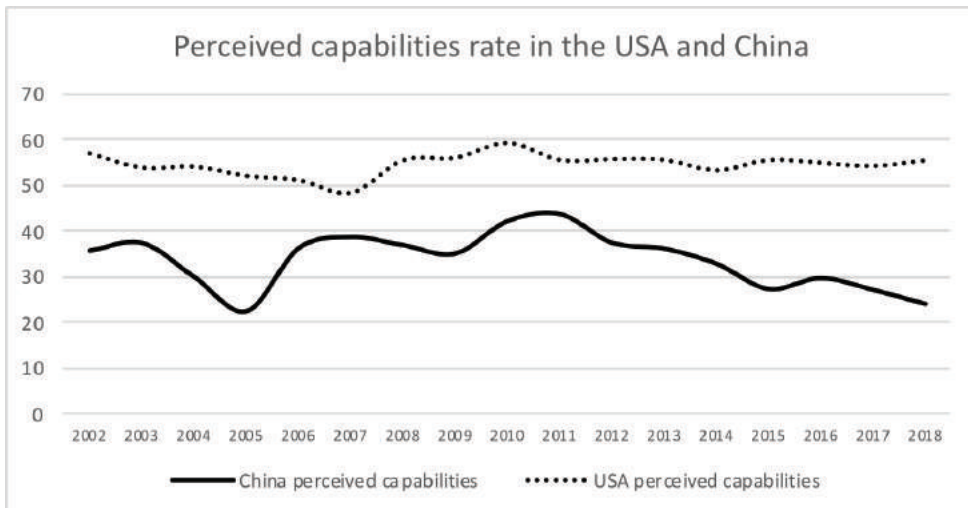


Figure 28.

Perceived capabilities rate in the United States and China. From GEM Data, by GEM, <https://www.gemconsortium.org/data>

However, in China, these two indicators are more complex and unexpected according to the TPB model, as shown in table 2. In China, the fear of failure rate has a negative relationship with entrepreneurial intentions, which is expected, but this indicator has a positive relationship with EI in the United States. Thus, the fear of failure rate in China may be a better indicator of EI than the motivational index and perceived opportunities. In general, the fear of failure rate in both countries increases over time. The high status to successful entrepreneurs rate has a negative relationship with entrepreneurial intentions in China and the positive relationship with EI in the United States. The entrepreneurship as a good career choice rate and the high status to successful entrepreneurs rate show a similar trend; however, before 2011, the entrepreneurship as a good career choice rate and EI in China had a negative correlation (-0.60). People in both countries are more likely to believe successful entrepreneurs have high status than to think entrepreneurship is a good career choice. Entrepreneurial framework conditions in China and the United States are better than the world average: the United States is famous for its culture and social norms and China's physical infrastructure and internal market dynamics, both significantly affected and determined by the Chinese government, are especially good. Chinese government policies aiming to encourage entrepreneurship intentions and activities are also potential factors involved when considering the determinants of entrepreneurial intentions. EI have a slightly positive relationship with perceived capabilities in both countries. However, the level of perceived capabilities is

consistently higher in the United States than in China, and cultural differences may play a role here.

Since attitude and subjective norm indicate perceived desirability, and perceived behavioral control indicates perceived feasibility, the two general hypotheses of this study can be tested. The results are shown in table 1. Overall, the correlations between EI and their determinants in the United States are more straightforward, unlike in China, where different periods have different patterns. In the United States, H1(perceived feasibility positively influences entrepreneurship intention) is true but weak, requiring future studies, but H2 (perceived desirability positively influences entrepreneurship intention) is true for every determinant of EI. The TPB model works very well in the United States in terms of identifying the determinants of entrepreneurial intentions. However, in China, the TPB model does not work so well: H1 is true but weak, as in the United States, and H2 is partially true. There are some time nodes, such as 2010, 2006, and 2013, that may need further research regarding what happened in these years that influenced entrepreneurial intentions in China. The disparity of results between China and the United States may be partially due to wider economic and political-institutional differences in the two countries, and differences in entrepreneurship framework conditions, including infrastructure, internal market dynamics, and culture.

Table 1. Table of Results

	The United States	China
Entrepreneurial intentions	Lower	Higher
<i>TEA</i>	<i>Strongly positive (0.80)</i>	<i>Positive (0.54); Strongly positive since 2010 (0.88)</i>
<i>Motivational index</i>	<i>Positive (0.49)</i>	<i>2010–2012: perfectly negative (-1.00); 2013–2018: strongly positive (0.90); Overall: negative</i>
<i>Perceived opportunities</i>	<i>Strongly positive (0.83)</i>	<i>2002–2006: strongly negative (-0.96); 2006–2018: strongly positive (0.73); Overall: little correlation (0.08)</i>
<i>Fear of failure</i>	<i>Positive (0.71)</i>	<i>Overall: negative (-0.68); 2013–2018: positive (0.45)</i>
<i>High status to successful entrepreneurs</i>	<i>Overall: positive (0.54); 2003–2005: perfectly negative (-1.00)</i>	<i>Negative (-0.46)</i>
<i>Entrepreneurship as a good career choice</i>	<i>Positive (0.42)</i>	<i>Positive (0.69)</i>
<i>Perceived capabilities</i>	<i>Slightly positive (0.11)</i>	<i>Slightly positive (0.22)</i>

6. Limitations and Implications for Future Research

This study is subject to some limitations. First, like the vast majority of studies in the literature, this study's focus is on entrepreneurial intentions rather than actual behavior (starting up businesses). Although the predictive validity of intentions has been established in a general context, it has yet to be established in the entrepreneurial context. As a consequence, this study is unable to predict how many people will actually carry through with their EI. A longitudinal study could reveal a better understanding of whether EI actually turns into entrepreneurial behavior. Second, this study used a selection of variables that were found to be most influential in predicting EI through extensive literature review, but other variables could be also important. Finally, this study examines the Chinese and Americans, thus the findings may be mostly generalizable to these two countries and similar countries instead of to less developed countries. However, the research framework provides a meaningful understanding of the topic and other researchers can apply it in different contexts in the future.

This research aims to enhance the existing literature on the determinants of entrepreneurial intentions. It further identifies the disparity between China and the United States regarding entrepreneurship framework and economic institutions. Scholars can see the differences between the determinants of EI in China and the United States. Therefore, for future studies, there are other questions that researchers could continue exploring. Because this study mainly identifies the disparity between the two countries, might the determinants of EI differ in other countries, especially less developed countries? This question is also important and would be worth examining, since less developed countries are the ones that need the most help from the rest of the world, including academia. Knowledge about the determinants of EI could be utilized to encourage entrepreneurship activities and foster economic growth in developing countries. Besides, the reasons behind various kinds of patterns identified in this study could also be further studied, since this study does not establish the causation between EI and its determinants; instead, the majority of reasons stated in this study are correlated possible reasons that are not yet proved.

7. References

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A Complex Networks Approach to Analysing the Erdős-Straus Conjecture and Related Problems

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Abstract

For any positive integer $n \geq 2$, the Erdős-Straus Conjecture claims that the Diophantine equation $\frac{4}{n} = \frac{1}{x} + \frac{1}{y} + \frac{1}{z}$ has a solution where x, y, z are also positive integers. In this paper, a directed network based on this equation is generated, with properties such as its average clustering coefficient, average path length, degree distributions, and largest strongly connected component analysed to reveal some underlying trends about the nature of the conjecture. Potential connections between different numbers, that result from satisfying a source-solution relationship for this equation, are described using the appropriate number-theoretic interpretations wherever possible, while conjectures backed by these trends are made in other instances. Additionally, a directed configuration model is used to show that the origin of several results is the degree sequence of the network. Metrics relating to the prime number nodes, specifically their in and out degrees, are also explored to yield some intriguing observations. On the whole, the aim is to highlight the viability of complex networks as a computational tool to study this general class of problems pertaining to fixed-length unit fraction splits.

Introduction

The utilisation of networks as a tool for computational analysis has undoubtedly become commonplace in a range of fields both in the physical and mathematical sciences as well as the social sciences. The inherent ability of networks to provide a large-scale overview of highly intricate systems simply based on fairly objective 'relationships' between their elements is effectively what makes them so versatile and more importantly, applicable to the real world. This paper, through the various observations presented, will attempt to not only provide a different perspective of a long-standing number theory conjecture but in the process display the usefulness of a complex network representation as a heuristic approach.

The conjecture, formulated by Paul Erdős and Ernst G. Straus in around 1950 [6], states that the following Diophantine equation has a positive integer solution triplet (x, y, z) for all integers $n \geq 2$:

$$\frac{4}{n} = \frac{1}{x} + \frac{1}{y} + \frac{1}{z}$$

It is important to note that this paper will assume that the solutions are distinct, thereby forming a three-term *Egyptian fraction* representation of $4/n$, and are in increasing order. This helps in making the computations much faster as fewer solutions need to be found. However, the nature of the problem is not affected as: if there exists any solution triplet, then there must also exist a solution triplet with distinct integers for $n \geq 3$ ($n = 2$ is an exception with a trivial known solution) [5]. Considering that the conjecture solely requires that at least one solution exists for the equation, this assumption has previously been made by several researchers. Additionally, it is clear that the conjecture only needs to be solved for the primes as all positive integers (except the unit 1) are multiples of some prime, and therefore must have solution triplets in which x , y , and z are also the same multiple of their prime divisor's triplets. This is exactly why the prime number nodes in this paper's network representation are analysed independently as well.

For some more context, the Erdős-Straus Conjecture is to date unproven. Analytical proofs have achieved significant partial results with a focus on solving for n in different residue classes. The strongest results using this method were obtained by Mordell [12] who proved the conjecture for all n except for primes congruent to 12, 112, 132, 172, 192, or 232 mod 840 which could thereby hold counterexamples. Apart from being used in known sieve theoretic methods, these soluble classes have also supported efficient computational verification, with Swett [19] verifying it for $n \leq 1014$. A similar conjecture for $5/n$ was made by Sierpiński [17] with the more generalised version of this problem class coming from Schinzel [14].

Model

In this section, a simple directed network model, briefly termed the Erdős-Straus Conjecture (ESC) graph, used to represent the Diophantine equation is introduced. The function $S(n)$ outputs an unordered set of integers that appear as part of any of the solutions to the equation. $D(n) = \{k \in \mathbb{N}: k \leq n\}$ and is the set containing all the denominators that have been solved for. The graph itself is denoted by $G_{ESC}(n)$ with its vertex and edge sets being defined as follows.

Vertex Set:

$$V(n) = D(n) \cup_{i \in D(n)} S(i)$$

Edge Set:

$$E(n) = \{(s, t) : \forall t \in S(s) \text{ for each } s \in D(n)\}$$

Essentially, $G_{ESC}(n)$ represents a simple directed network where all the denominators that have been tested produce directed edges to all their unique solution integers, even if it includes themselves (self-loops), in each of the respective triplets. This implies that the tested denominator always has an out-degree greater than or equal to 3 unless a counterexample is found. $S(n)$, which is fundamental to find the target nodes, requires all the Egyptian fraction splits to be found for any denominator. There are multiple construction algorithms that can be used to do this including the relatively popular Fibonacci-Sylvester Greedy algorithm and Golomb's method [9]. However, in this paper an open-source Python implementation [8] of Dr. Ian Stewart's Short Sequence Method for recursive brute-force [18] is used as it proved sufficient for all computations done here.

There are a number of ways this equation could have been modelled as a network, with undirected graphs and directed multigraphs both options, as in the case of the latter, the number of times a solution integer is referenced by an n (source denominator) can also be counted via the parallel edges. However, to simply observe and track the unique n -solution relationships between different integers, this representation was deemed adequate, for reasons of more efficient computation and possibly, reduced mathematical 'noise' that will make analysis easier without affecting any fundamental conditions of the conjecture itself.

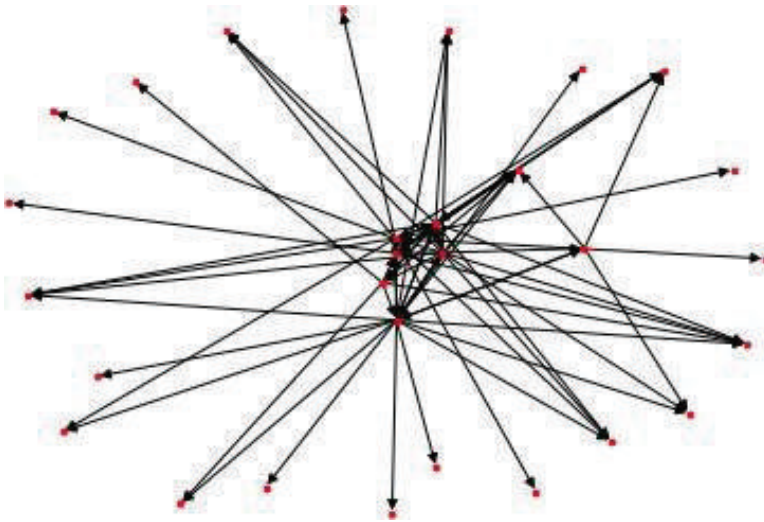


Figure 1.
 $G_{ESC}(10)$ with 29 nodes and 79 edges

Degree Distribution

The degree distribution of the network is an interesting metric to look at as it offers a holistic glimpse into its potentially scale-free nature. In this case, the in-degree sequence would be a more logical choice as it would reveal the tendency of certain numbers to be solutions to the equation more often than others—thereby, possibly yielding the extent of preferential attachment embedded into the mathematical depth present.

It is also important to note at this point that the Largest Strongly Connected Component (SCC), almost always contains all source-denominator nodes (solved n -values). This is a highly useful observation as it implies that as the number of n -values tested tends to infinity, which would be the required case for proving the correctness of the conjecture, all positive integers become a part of the largest SCC. Therefore, analysing this as a sub-graph might help gain insight into the properties of the network that might be present at $G_{ESC}(\infty)$ —and will therefore be a recurring tool in this paper.

Scale-free networks, whose degree distribution follows the power law [1], usually have

$$P(k) \sim k^{-\gamma} \text{ (where } 2 < \gamma < 3 \text{)}$$

From *Figure 2*, it is clear that the overall network has some level of preferential attachment with $\gamma \approx 1.80$. However, this apparent preference for some solution integers over others seems to disappear in the largest SCC as $\gamma \approx$

0.546 in Figure 3. The reason for this observation is simply the existence of a finite number of integers with a high number of factors versus an infinite number when n -values also tend to infinity. This is because the conjecture can effectively be restated as

$$\frac{4}{mp} = \frac{1}{mx} + \frac{1}{my} + \frac{1}{mz}$$

where p is any prime.

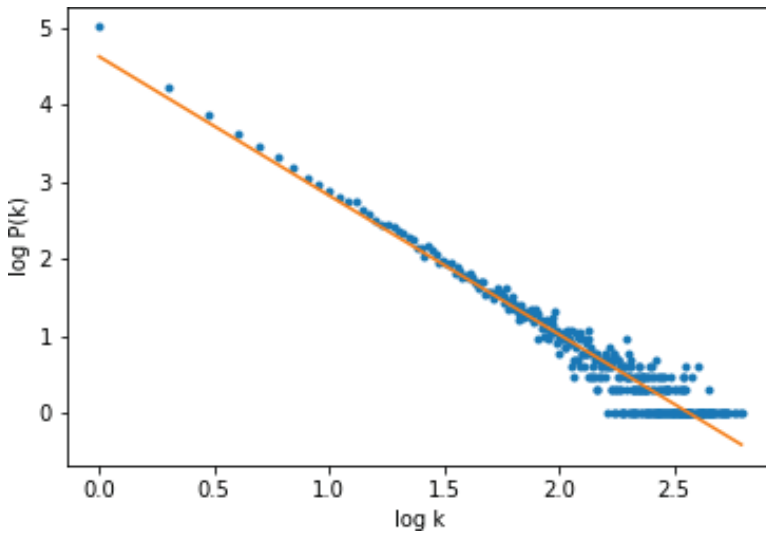


Figure 2.
In-degree Distribution for $G_{ESC}(1000)$

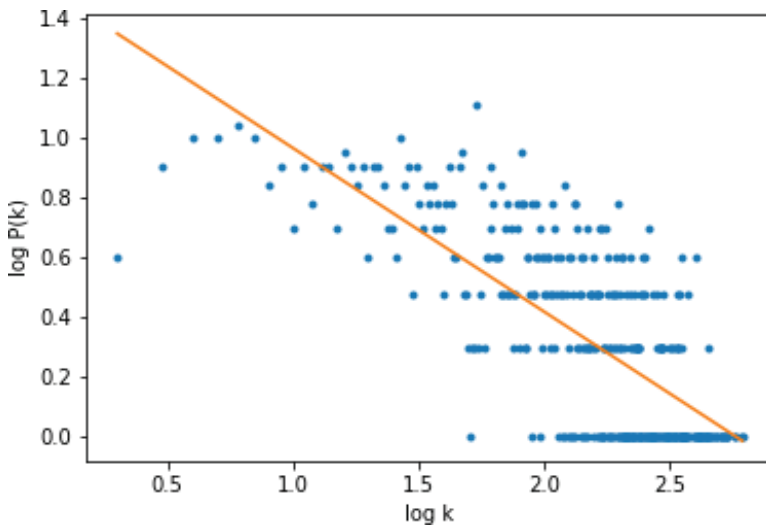


Figure 3.
In-degree Distribution for the Largest SCC of $G_{ESC}(1000)$

Similar to the reason for why the conjecture needs to be solved only for the primes—the solution sets for composites are simply multiples of the solutions sets of their factors. Therefore, the more factors a number has, the more likely it is to show up as a solution (and in fact, even a source i.e. high out-degree) as it would simply be a different multiple of some base solution triplet. This justifies the preferential attachment when $G_{ESC}(n)$ is computed for a relatively small n like 1000. However, as this $n \rightarrow \infty$ these high-factor numbers are no longer the ‘centres’ but instead the probability of being a solution also spreads out amongst the now abundant (or ideally, infinite) number of high-factor integers. The in-degree distribution is consequently imperative to understanding many other core metrics of the network.

Average Shortest Path Length

The average shortest path length (directed) was computed using the standard formula,

$$a = \sum_{s,t \in V(n)} \frac{d(s,t)}{x(x-1)}$$

where x is the number of nodes.

The value is < 1 because in the full network most nodes are only present as they are solutions and have not themselves been solved for as sources, therefore resulting in shortest path lengths of 0 to all other nodes by default. Consequently, *Figure 4* can be considered as a mere artifact of computing the average path length for directed graphs. Although this makes the largest SCC sub-graph far more pertinent, one intriguing non-trivial deduction that explains the exponential decrease in the average path length with the growth of the network is that the number of solutions which are a lot larger than the source are also exponentially more frequent than solutions less than the source node being solved (as those would have non-zero path lengths). Since this must be reflected within the degree sequence of the network, a random network based on this degree-sequence was generated using a directed configuration model [13]. As expected, the average path length did appear to have its foundations here as the random network yielded an identical average shortest path length to the actual $G_{ESC}(1000)$ network (value not considered in *Figure 4*).

For the largest SCC, however, the value appeared to be approaching 2.0 even though a rigorous proof for stabilisation could not be deduced. In *Figure 5* the largest components calculated are until approximately $G_{ESC}(600)$, enough to judge the general trend, although by $G_{ESC}(1000)$ the value is almost exactly 2.0, and 2.03 by $G_{ESC}(2000)$ indicating slowing growth and hence possible future stabilisation. This might also be of interest as it implies that

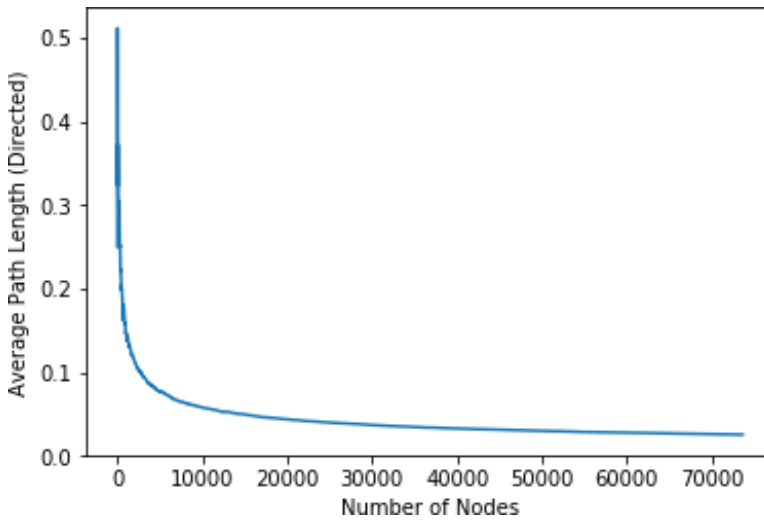


Figure 4.

Average Path Length (Directed) against the Number of Node

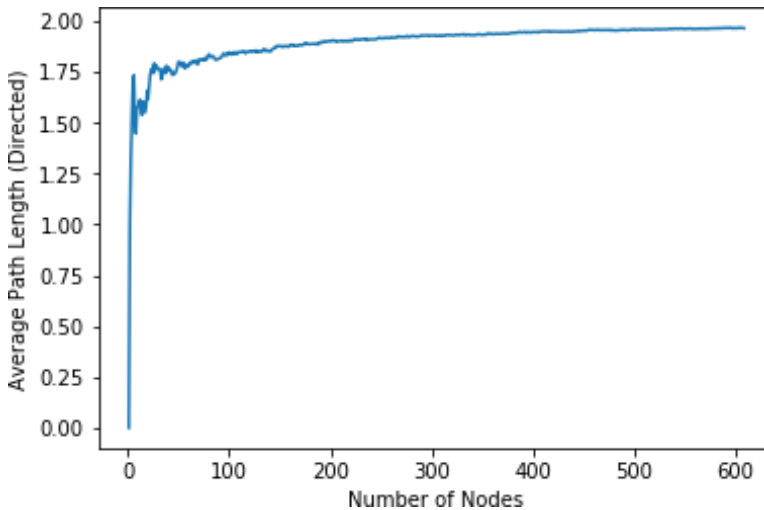


Figure 5.

Average Path Length (Directed) against the Number of Nodes in Largest SCC

once again, as n -values tend to infinity almost every number would be able to reach another within about two edges. Although this paper will not look to expand on any analytical mathematical proofs, this seemingly incredible answer probably does have some intrinsic tie with the previously stated fact that almost all solved n -values are part of the largest SCC immediately (with at most minor delays for some primes).

Future study on the relation between the solutions of a specific n and solutions of these solution integers themselves may help speed up the Egyptian

fraction splits for this conjecture as the prediction can be based on the fact that the number should only be at most a fixed distance away (here approximated to be 2.0) in this network representation for sufficiently large n -values, possibly for some form of a more computationally cheaper brute-force.

Furthermore, the largest SCC of the random degree-sequence based network was in fact very similar with five nodes less, even though it had about 27000 edges less and a significantly lower average degree as a result. Most interestingly, it too had an average shortest path length of almost exactly 2.0 again reiterating the point that the degree sequence is the likely reason behind most path-length properties observed.

Average Clustering Coefficient

The clustering coefficient (directed) was computed using the formula [2],

$$c_u = \frac{1}{deg^{tot}(u)(deg^{tot}(u) - 1) - 2deg^{\leftrightarrow}(u)} T(u)$$

where $T(u)$ is the number of directed triangles through node u and $deg^{tot}(u)$ is the sum of in-degree and out-degree of u and $deg^{\leftrightarrow}(u)$ is the reciprocal degree of u .

Averaging it out for each node,

$$C = \frac{1}{x} \sum_{v \in G_{ESC}(n)} c_v$$

where x is the number of nodes.

To explain the clustering present in the network (only the largest SCC would be of relevance here as others would not have out-degrees), the most plausible approach was to observe the numbers forming these directed triangles. The 030C type triads (directed triangles) were therefore sampled and manually analysed via a triadic census [21]. Once again, similar to the path-length observations, the triangles appeared to be constructions of a probabilistic model, as when the n and the solution nodes share a prime factor, there exists the greater chance of forming the edge. When these node pairs sharing prime factors form a loop of three, it happens to complete a directed triangle. The key, however, lies in a second trend—no directed triangle with all three nodes as primes was found. Although it is possible for a prime to have a prime solution, it was unclear as to why these loops did not form with all three primes or whether the sample sizes taken were simply not sufficient, in which case, the rarity of these occurrences would be a point of note.

This, however, would suggest that the average clustering, which references the fraction of complete triangles, can be estimated by using the prime count [23]. For $n > 10$, a reasonably accurate estimate was found to be

$$C_{estimate} = \frac{2\pi(n)}{n}$$

where $\pi(n)$ is the prime counting function

A central caveat before interpreting this result must be that no concrete mathematical proof or combinatorial argument to explain the triangle formation could be found and that this expression, using the prime number theorem [22], itself becomes

$$\frac{2\pi(n)}{n} \sim \frac{2}{\ln(n)}$$

which might make it a co-occurrence as such logarithmic growth can often be seen in a range of models across the natural sciences and mathematics.

Primes

Considering the importance of primes to this conjecture, and their uniqueness in terms of ‘immunity’ to any factor-based trends unlike the composites, it was deemed that the metrics of the primes were a major facet for exploration. Specifically, the out-degrees and in-degrees were looked into as they would be representative of the number of solutions source primes have (i.e. when n is prime) and the number of times a prime itself is a solution to the conjecture’s equation respectively.

Figure 7 is almost identical with respect to the distribution and structure to the graph obtained by Elsholtz and Tao [4] when counting the number

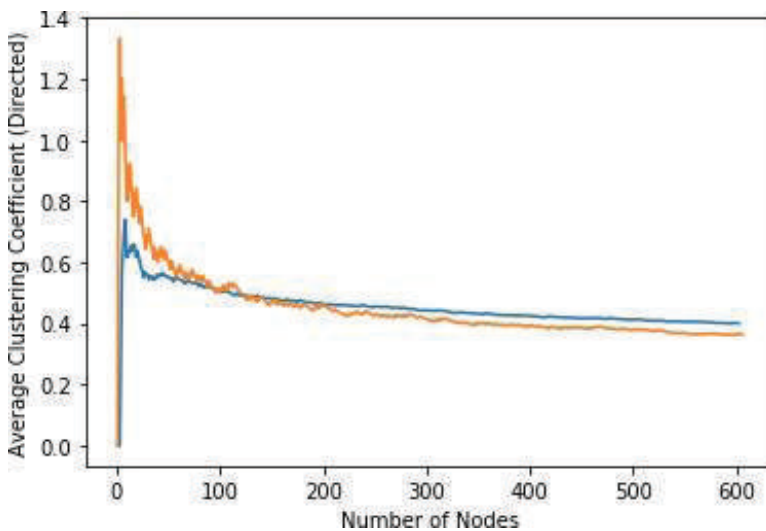


Figure 6.

C (Blue) compared to the $C_{Estimate}$ (Orange) against the Number of Nodes in Largest SCC

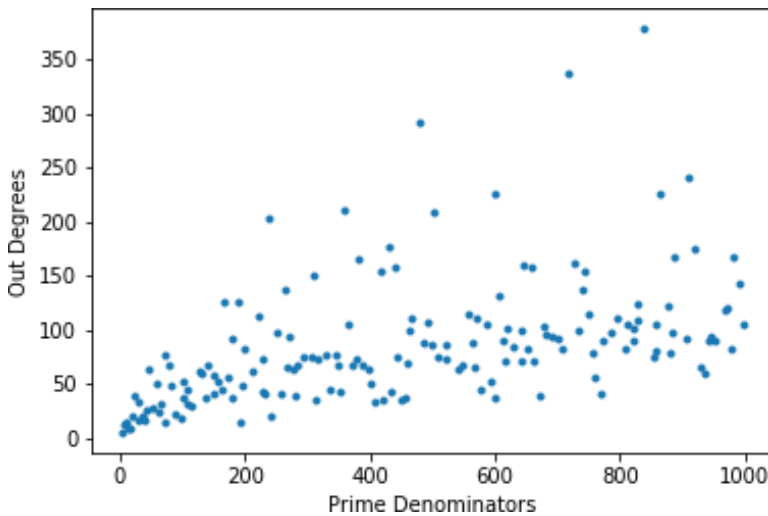


Figure 7.

Out-degrees against the Source Prime Denominators

of solutions $f(p)$ for all $p \leq 1000$, indicating that the out-degree is in fact, a fairly reliable metric to monitor this seemingly random number of solutions for the range of primes. The asymptotic bounds proven in the paper were

$$N \log^2 N \ll \sum_{p \leq N} f(p) \ll N \log^2 N \log \log N.$$

A similar scaling for these upper and lower bounds in terms of the out-degree could also possibly be derived although this line of investigation was beyond the scope of this paper.

In-degrees (*Figure 8*), illustrate another notable trend, showing that some primes seem to occur far more often as solutions than others, and that the peak appears to be quite distinct (for $p \leq 1000$, this peak occurs at the prime 211 with an in-degree of 125). The smooth curvature, without too much randomness or outliers from the clearly seen trend, of the graph also seems to point at a deeper underlying cause for this phenomenon. Although this trend might change significantly as more prime denominators are tested, it would still remain an intriguing point of subsequent mathematical study.

Other Trends

Self-loops. Considering that self-loops are allowed in this directed network model, when they occur they imply that the Erdős-Straus Diophantine equation would simplify to

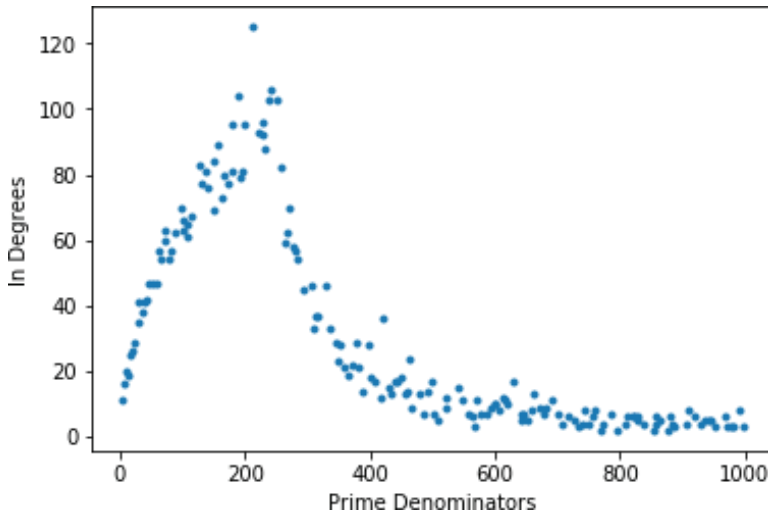


Figure 8.

In-degrees against the Source Prime Denominators

$$\frac{3}{n} = \frac{1}{y} + \frac{1}{z}$$

assuming that x was the solution equal to n , without the loss of generality. It is known that this equation has solutions if n has a factor congruent to 2 mod 3, with Klee and Wagon [20] attributing this result to Nakayama without a citation. Therefore, self-loops were observed for only these values of n as nodes in the $G_{ESC}(n)$.

Largest SCC. As noted previously, a key observation in this network was the near continuous presence of all solved n -values in the largest SCC barring minor delays in joining the component for some primes. The delays could be partially deduced from the fact that the plot of the number of nodes in largest SCC against the solved denominators (not shown) was not completely straight (occasional slight curvatures) even though it displayed a strong directly proportional trend on the whole—although the reason as to why the numbers observed with this lag in this range were only primes forms another potential extension of this trend. That this holds from almost the initiation of the node generation process is what is most surprising, and monitoring this for far larger ranges of n might yield other useful results.

Growth of Network. The network, as seen in Figure 9, grows on an exponential rate. The reason for this most certainly has a relation with another bound referenced by Elsholtz and Tao [4], and proven by Heath-Brown [11] in a private communication (strongest version of this bound), where the lower

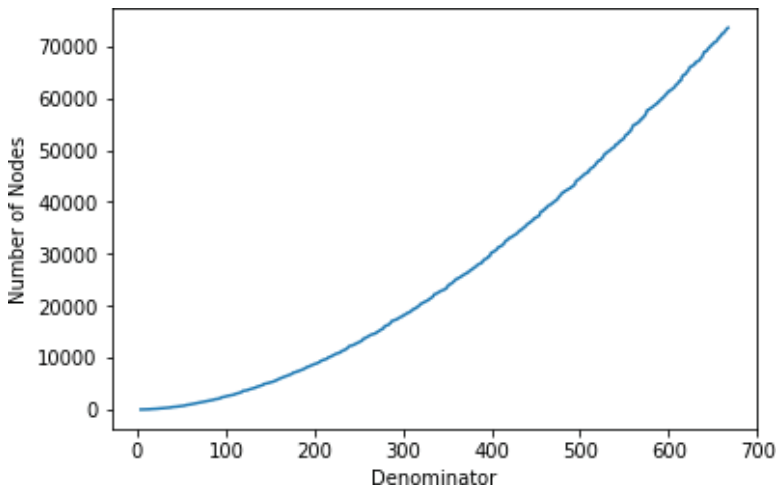


Figure 9.

Growth of the Network with the Number of Source Denominators Solved

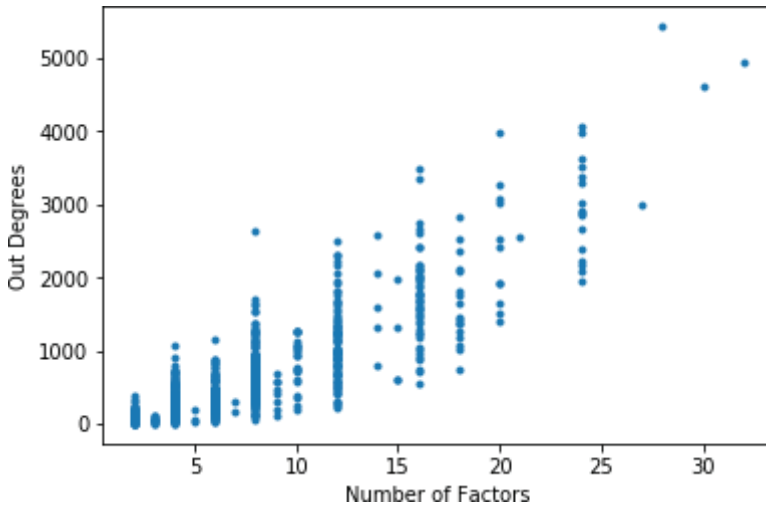
bound for the sum of the number of solutions $f(n)$ increases at an exponential rate,

$$N \log^2 N \ll \sum_{p \leq N} f(p) \ll N \log^2 N \log \log N.$$

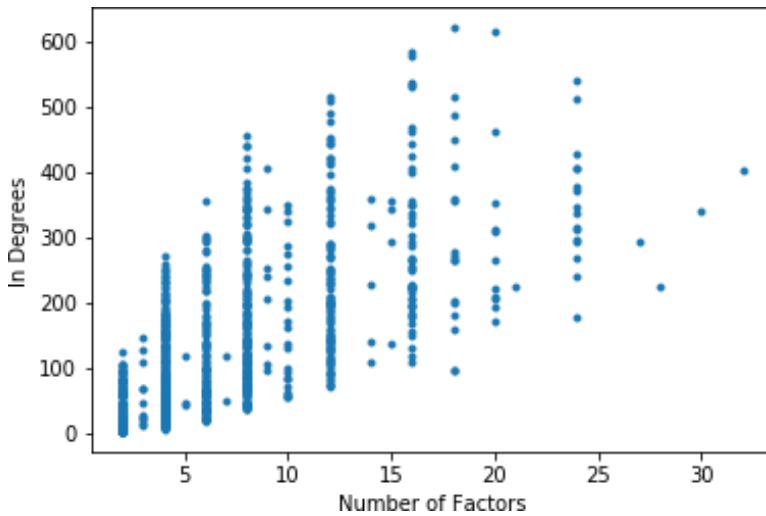
implying a similar growth for the number of nodes in the network representation (size) as well, as it too represents an aggregate value like the sum above.

Number of Factors. The effect the number of factors source nodes have on their number of solutions has been another recurring point in this paper and is critical to putting the other properties of the network into context. As given in the explanation for the degree distribution, it presumably comes down to a high number of factors giving an integer a higher probability of appearing as a source or solution (for out and in degrees respectively). The roughly proportional trend between the number of factors and both the degree sequences is illustrated below for all solved denominators, but not within a separate sub-graph like what was used for the degree distribution computations (thereby making it imperative to note the room for change with a larger range, for the in-degree graph). However, factors certainly cannot be the sole element driving the metrics, with the sequences for primes not affected by this as stated before, and with the same number of factors leading to notably varying out-degrees in general (vertical data-points in the graphs).

Sierpiński's Conjecture. An identical directed network model was computed for Waław Sierpiński's variation of this conjecture [17] which states that for all $n \geq 2$, the following Diophantine equation has solutions.

**Figure 10.**

Out-Degrees of nodes against their Number of Factors

**Figure 11.**

In-Degrees of nodes against their Number of Factors

$$\frac{5}{n} = \frac{1}{x} + \frac{1}{y} + \frac{1}{z}$$

Trends near identical to those seen in the Erdős-Straus network were observed in this network too, indicating a certain similarity between the underlying number-theoretic structures of these two equations. The parallel trends included the largest SCC that almost always consisted of all source

nodes, degree distributions, average clustering coefficients (in fact, close in raw values as well to $G_{ESC}(n)$), approximately equal average shortest path length when compared to its degree-sequence based random network (also comparable to the $G_{ESC}(n)$ 2.0 value for the largest SCC), the in and out degree prime node trends, the growth rate, and the average effects on the degrees of nodes by the number of factors they have.

Conclusion

In the end, the paper provides a range of fascinating insights into this conjecture wrapping back to the main goal of presenting a complex networks representation as a different and useful approach for not only the *Erdős-Straus Conjecture* but also easily extendable to this category of related problems that require fixed-term unit fraction splits. The real value would, however, abide in transcending many of these experimental trends into rigorous mathematical proofs, especially for the several probabilistic arguments that determined most of the analysed metrics.

Network analyses in pure mathematics, and more specifically in number theory, have witnessed rapid growth in recent years in terms of the work done in the study of prime numbers [7], divisibility patterns [15], and a wide array of other integer sequence based networks [3, 16, 24]. As increasingly standardised techniques specialised to this domain are developed to bring greater context, usability, and accuracy to the interpretations offered by these networks, the scope of such research would most definitely be augmented as it can then function in a better known framework more pertinent to the mathematical analysis being conducted.

As for the problem deconstructed here, it was most intriguing to find that the random directed configuration model based only on the degree sequences, and therefore the appearance of these different integers as source nodes or solutions in the Diophantine equation, produced a relatively accurate estimate of the overall network. Furthermore, this was construed without any of the mathematical depth evoked by the individual numbers themselves—indicating a greater than expected extent of symmetry and predictability in the number of solutions and the growth of that quantity with n . While many of these trends such as the continuously source-capturing largest SCC, average path length, and the average clustering act as pointers to their own unique properties of the conjecture, perhaps even hinting at its correctness due to the presence of a non-trivial degree of evolving interconnectedness, the answer as always will continue to remain amongst the beautiful yet incredibly elusive primes.

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An Institutional Analysis of the Military's Role in the Egyptian Economy

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1.1 Introduction

After nearly 30 years of political stability under former president Hosni Mubarak, the Egyptian Revolution of 2011 upset the status quo and became a major turning point in Egyptian history. Nearly a decade after the revolution, major questions still remain. Was the revolution a turning point for the better or worse? Was the revolution worth it? This paper will aim to answer the question: what has changed about the military's role in the Egyptian economy since the revolution?

Mubarak brought an unprecedented level of stability, a friendly business environment (although one dominated by those close to him), and large amounts of foreign investment. After a rather successful era of reform and opening up in the 1980s and 1990s, the liberal market economy was set to grow (Fahmy 2012). Egypt was growing rapidly in the 2000s, especially after 2005. In the five years prior to the revolution, growth was around 7%, unemployment was at a historic low, public debt fell by 1/3, and foreign direct investment was at record highs of \$46 billion between 2004 and 2009 (Bakr 2013). Despite the seemingly impeccable statistics of growth, especially compared to developing countries, there were problems embedded deep in in society, politics, and the superficial economy. There are two negative defining traits of Mubarak's reign: superficial development and crony capitalism (Amin et al. 2012).

The military during this period played a rather insignificant and limited role in the economy compared to previous periods and after the revolution. Mubarak consistently provided material privileges, allowing officers to profit from post-retirement positions without proper oversight in order to secure

loyalty (Fahmy 2012). Though retired senior officers often took high-level civilian jobs and lucrative business positions (especially those owned by the state or military), the military did not take up a large share of the economy. This method of controlling the military was significantly different from that of Sadat and Nasser. Instead of frequently shuffling leaders and using ideological goals along with external war, Mubarak relied heavily on material rewards (Marshall 2015). Nasser established state-owned production while Sadat solidified the military's role in the civilian economy. However, the Egyptian Armed Forces (EAF) played a minor role in development and the economy under Mubarak, unlike in previous periods (Fahmy 2012).

After the revolution of 2011, much like after any political shock or instability, the economy went into a recession. One of the major problems was security after the police withdrew from the streets. Investment and business confidence decreased due to a lack of security and mass strikes and protests around the country. The recovery was slow for a then devastated economy, creating many problems for the interim and Morsi governments, and partially causing the downfall of the Muslim Brotherhood. For five years after the revolution, economic growth remained around 2.5%, and unemployment was high (World Bank 2019).

Defense Minister turned President Abdul Fattah el-Sisi promised to bring economic reform and revive the economy. Though in recent years the growth rate has increased a little, many scholars argue that the situation under the military-dominated government has become worse, especially in the long run. Poverty rates have risen (using the national standard poverty line) just like before the revolution, while the fundamental problem of inequality has not improved (World Bank 2019). The EAF now dominates the political economy, and controls the critical enterprises in the economy, using its influence to protect its own interests and stifle other private businesses (Marshall 2015). This situation has become increasingly evident as an obstacle to long term and successful economic development. To be fair, the military has successfully improved people's lives in the short term, mainly because it has improved the public sector. Military businesses are more trustworthy in the eyes of local Egyptians because the private sector over a long period of time has been dishonest, primarily through crony capitalism (Marshall 2015). However, there is a question of whether the large state-run projects dominated by the military will improve the economy and people's lives in the long term.

The shortcomings of the Mubarak regime have been well studied since its fall, and a variety of explanations have been given about the causes of the revolution. Comparatively, little work has been done on the change in the military's role in the economy and its implications. There is no existing

consensus on the economic aftermath of the revolution and whether economic development has become better or worse. This paper aims to conduct a traditional institutional analysis of the Egyptian military, where institution is defined as an organization in the economy. Specifically, this paper will analyze the role of the military in the Egyptian economy and how it has changed since the revolution. Implications of such changes for economic development will also be discussed.

1.2 Literature Review

With or without the military, economic grievances and institutional problems have plagued Egypt since the Mubarak era. The issues of development that existed before the Egyptian Revolution of 2011 have largely persisted through the subsequent tumultuous times, leading to a failure overall to implement effective reforms in the country. The revolution marks a re-emergence of military power in the economy. Existing literature extensively analyzes the causes of the revolution and the economic situation before the revolution. This paper aims to fill the gap in the literature about the military's influence on the economy and how it has changed.

Uprisings have been attributed to a variety of factors. Some argued that crony capitalism and political corruption were central to the revolution (Sorenson 2011; Fahmy 2012). Roccu (2013) described socioeconomic preconditions as the central factor leading to the revolution. Others similarly argued that economic failures and a mismatch between education and opportunity caused significant dissent (Campante and Chor 2012; Bakr 2013). Many scholars also thought economic inequality and unemployment caused the revolution (Korotayev and Zinkina 2011; Hassine 2011). A lack of political progress compared to its rising economic position, and a suppression of democracy, limiting participation of the educated middle class, also contributed to the downfall (Fukuyama 2011). Huntington is partially correct in his book *Political Order in Changing Societies* about this situation: without political development, modernization would lead to tyranny, civil war, and mass violence. These various arguments clearly reflect the complex nature and scope of the grievances before the revolution. The best summary of these issues may be what people were chanting on the streets in 2011: "bread, liberty and social justice."

Korotayev and Zinkina (2011) argued that demographics was the most significant cause of the revolution. Although unemployment was only 9.7%, not a high number for developing countries, almost half the unemployed were college graduates and young people 20–24 years old (Korotayev and Zinkina 2011). The notion that Gamal Mubarak was going to succeed his

father and continue to further the interests of the wealthy business owners angered many young college graduates who could not find jobs.

The Mubarak era can be best characterized by superficial development because it focused on large tangible projects that would attract foreign investment and show the populace that development was happening (Amin et al. 2012). Fahmy (2012) argued that the final decade of Mubarak's rule was characterized by rampant institutionalized corruption: crony capitalism. His son Gamal Mubarak and close associates managed to gain an unprecedented amount of wealth through deregulation and privatization of state industries, buying cheap land, and police corruption. Galal and Selim (2012) reviewed development in the Arab countries since WWII and blame underdevelopment on the extractive nature of political and economic institutions. The corruption and use of institutions to facilitate large business interests became one of the major grievances for the Egyptian people.

Immediately after the revolution, it was the Supreme Council of Armed Forces that took responsibility for setting up an interim government (Nassif 2013). The armed forces have traditionally had a strong role in politics (the previous three presidents were all former generals), and their support for the democratically elected government of the Muslim Brotherhood was critical to the success of the civilian government. This paper will show later that the withdrawal of that support due to conflicts of economic interest would eventually lead to the downfall of Mohammad Morsi.

After the Morsi era, which was characterized by crisis management, the EAF, under the leadership of former general Abdel Fattah el-Sisi, came into power through the 2013 coup. The country had been performing poorly with high unemployment and low economic growth. As during the Mubarak era, inequality of income grew and economic opportunities, especially in the rural areas among women and youth, were on the decline (Hassine 2011). The people of Egypt desperately wanted economic revival. While growth in the past was not equitable or fair, the current situation was not much better (Campante and Chor 2012).

Past studies have looked at the socioeconomic preconditions for military coups and the relationship between military coups and economic growth. There are only a few studies on military-influenced market economies, and most do not refer to the situation in Egypt, which is, at the moment, one of the extreme cases that has yet to be studied. Furthermore, there is a lack of in-depth analysis of the consequences of a military-controlled economy and a lack of consistent methodology for studying such a situation. In this kind of situation, most details are hidden and there is no authentic, transparent data, so there is no clear statistical way of measuring the influence of the military on the economy (Siddiqi 2017). To calculate the value of military

intervention in the economy, the value of the resources exploited by the military and its cronies must be included. Qualitative analysis of primary sources (e.g. interviews) and secondary sources (news reports and financial reports of the large companies affiliated with the military) are used instead (Siddiqua 2017). The qualitative analysis highlights certain, but not all, of the consequences of military involvement.

However, it is still possible to measure general economic development under the military regime through macroeconomic indicators and to look at key economic elements that are reflective of overall performance. McKinlay and Cohan (1975) used five categories: political variables, military variables, background economic variables, international trade variables, and economic performance variables.

Background economic variables include constant per capita gross national product (GNP), budget as a percentage of GNP, primary production as a percentage of GDP. These variables give a general understanding of the economy and the relative role the central government plays.

International trade variables include exports/imports as a percentage of GNP, international liquidity as a percentage of imports, goods and services balance, and private and foreign direct investment as a percentage of GNP. These variables give a general idea about how a country is situated in the international market, how well it may overcome short term difficulties, and its position in the private investment market.

Economic performance variables include the rates of growth of: constant per capita GNP; the cost of living; exports; the food index; and primary education. These variables show general economic development, whether there are destabilizing factors due to uneven income, and the general socioeconomic situation.

These factors can be analyzed across periods to compare the macroeconomic situation. Meyersson (2016) similarly looks at GDP per capita purchasing power parity (PPP) as an indicator for long term growth; and military personnel per population and military expenditure as indicators of military presence and strain on the economy. For the political environment, the Polity Index is used, and the number of years the sitting executive has been in power before and after the coup. Social violence is also taken into account through an index from the Cross-National Time-Series Archive (general strikes, assassinations, government crises, purges, riots, revolutions, and anti-government demonstrations).

In general, economic performance is poor after a military take-over, especially when transitioning into an autocracy. These events typically do not promote economic reforms or create stability. There has been found to be a negative effect on long term growth factors like human capital, health,

education, and investment (Meyersson 2016). The graphs below show Meyersson's analysis of three particular cases of military coups.

In the case of Egypt, only a limited number of existing studies describe military involvement because of the hidden nature of military operations. Traditionally, the Egyptian Armed Forces (EAF) was the "engineer of modernization" under Nasser and Sadat (Marshall 2015). It owned and operated large parts of the domestic manufacturing industry, and its budget and economic activities operated "off the books." When Nasser came into power, the military played a significant role in both politics and economics. Governor and business executive positions have been traditionally given to

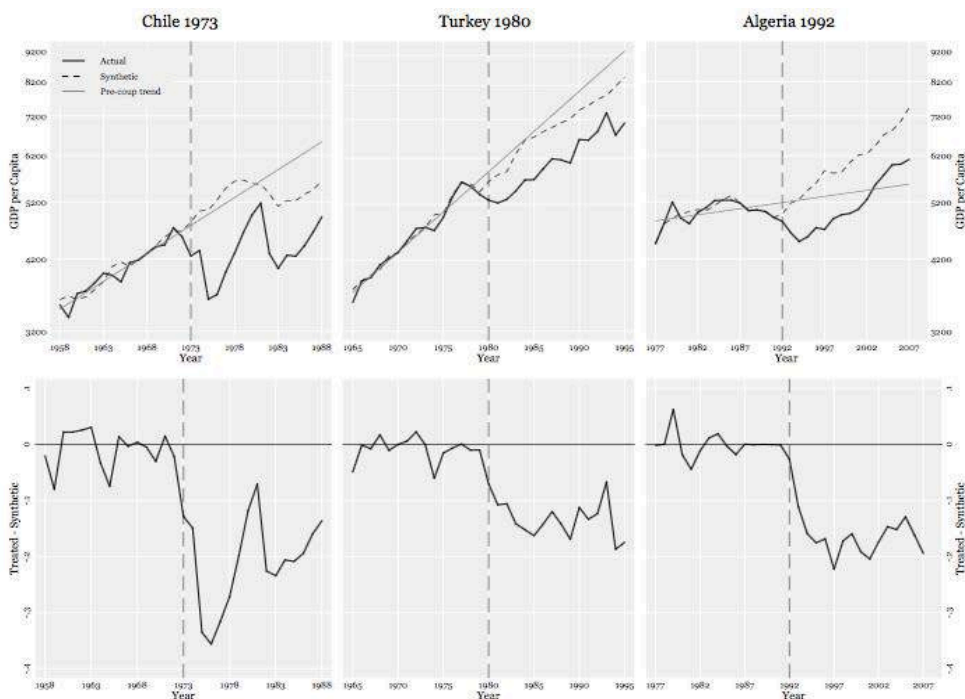


Figure 1.

Case Studies with Synthetic Controls.

"Notes: The upper graphs show the GDP (PPP) per capita (black line), pre-coup trend in GDP per capita (gray line), and an Abadie, Diamond and Hainmueller synthetic control (all in log scale), whereas the bottom graphs show the corresponding differences between the treated unit and the synthetic control, for Chile 1973, Turkey 1980 and Algeria 1992. Covariates used to calculate the synthetic control are log GDP per capita, growth in GDP per capita, log population, years since the last coup, and the number of past transitions to autocracy, as well as the individual GDP per capita values of the five years preceding the coup as covariates from which the weights are derived. Any control units eligible for receiving non-zero weights cannot experience a coup 15 years before or after the respective coup cases." (Meyersson, 2016)

former generals to secure further loyalty. At the time, there were common ideological goals for the military to work towards: providing social justice, nationalization, and fighting Israel (Magd 2011). Since Nasser had socialist policies and foreign security threats which both required military support, the military played a major political and economic role (Nassif 2013). The military provided technical expertise for industrialization projects, reform, public transportation plans, and building the Aswan High Dam. Abdel-Malek maintains that 1500 former officers were appointed to top nonmilitary positions between 1952 and 1964. During that time, there were major purges to rid Nasser of political opponents and opponents within the military. In 1953, the Revolutionary Command Council purged 450 officers because they were deemed untrustworthy (Abdel-Malek 1968). This method of controlling the military changed with Sadat and Mubarak, though the elite position of officers still remained.

The military's role was weakened under Sadat, as shown by military expenditure dropping from 17% of GDP to around 6% (Nassif 2013). Sadat comparatively shuffled the top officers frequently and encouraged factions within the military to maintain his power. He exploited the friction between officers to create competition since the leaders were generally replaceable (Nassif 2013). Despite the agenda of rapid marketization under Sadat, the military retained many of its businesses that produced civilian products. In fact, the production of civilian products actually increased due to the end of the war with Israel (Nassif 2013). The National Services Projects Organization (NSPO) was founded to employ military officers. The NSPO founded various commercial enterprises run by retired generals that enjoyed various subsidies and tax exemptions that were supposed to be granted to military enterprises for the sake of national defense. However, with trade liberalization and the end of Nasserist protectionism, foreign goods were let into the country, creating strong competition for both state-owned and military enterprises (Magd 2011). During the Mubarak era, the decline of these enterprises became more evident, as they were unable to compete with foreign companies.

1.3 Methodology

Part One of this paper will use data from the World Bank, the United Nations Development Programme (UNDP), and the European Bank for Reconstruction and Development (EBRD) to compare and analyze the basic indicators of economic development before and after the Egyptian Revolution of 2011. This includes the Human Development Index (HDI), annual GDP growth, GDP per capita growth, infant mortality rate, literacy rate,

primary completion rate, private sector participation, poverty headcount ratio at national poverty lines (% of population), foreign direct investment (FDI), and unemployment across different groups. The indicators are used to highlight certain macroeconomic issues and broadly assess the merits and failures of the non-military driven Mubarak era and the military driven Sisi era.

Part Two of this paper will discuss the military's role in the economy under Mubarak and then under Sisi. Cronyism and military influence are both hard to track through official venues, as most are not monitored by the state. This paper will look extensively into news sources, both local and international, in order to piece together a picture of influence. The nature of the Egyptian economy after the revolution is complex. It is hard to measure the impact of military influence on the economy statistically; this paper will look into key industries and the dealings of the military in an attempt to understand possible issues and the impacts of military control that are often not measurable by traditional methods and economic indicators. In particular, this paper will look into specific projects that show strong military involvement.

1.4 Macro Indicators

The overall economic performance for the last decade under Mubarak was good, but in terms of overall development, the results are much more mixed. GDP growth rate remained strong for the entire period, especially after 2004, where the growth rate averaged around 6 percent until Mubarak's overthrow. The growth rate was low for the four years after the revolution due to the event itself and other political shocks like the removal of Morsi in 2014. Growth only picked up slowly after Sisi came into power, but never reached the pre-revolution level and is currently around 4%, as shown in the graph below. The current management of the economy is questionable with recovery so slow, even in terms of GDP.

The high growth was promoted by liberalization and a business-friendly environment. It also led to a great increase in foreign direct investment, reaching 9% of the GDP in 2006. Egypt was one of the hottest developing countries to invest in, but after the revolution, investment declined significantly and never regained the pre-revolution levels despite efforts by Sisi to attract foreign investment (World Bank 2019). Domestic credit to the private sector shows how much of a presence the private sector has in the economy. The percentages reflect Mubarak era's private-led growth. After the revolution and under Sisi, the percentage has fallen, confirming that the public sector led by the military plays a greater role in the economy. According to

Table 1: Macro Indicators.

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Mortality rate, infant (per 1,000 live births)	39.40	37.30	35.40	33.70	32.20	30.80	29.60	28.40	27.30	26.20	25.20	24.30	23.30	22.40	21.60	20.90	20.10	19.40	18.80	
Poverty headcount ratio at national poverty lines (% of population)	16.70					19.60				21.60		25.20		26.30			27.80			
HDI	0.605	0.611	0.616	0.620	0.622	0.628	0.634	0.642	0.650	0.658	0.660	0.665	0.668	0.675	0.680	0.683	0.691	0.694	0.696	
Primary completion rate, total (% of relevant age group)	89.14	87.55	86.25	85.55	86.44	88.60	90.32	86.84	91.94		97.17	100			100			93.94	94.96	
Literacy rate, adult total (% of people ages 15 and above)							71.41	66.37	..	..	..	72.05	..	73.87	75.06	..	..	..	..	71.17
Domestic credit to private sector (% of GDP)	52.00	51.95	54.93	54.66	53.90	54.04	51.17	49.29	45.52	42.80	36.09	33.07	31.15	27.39	26.22	25.61	26.32	34.13	28.52	25.55
Foreign direct investment, net inflows (% of GDP)	1.17	1.24	0.52	0.74	0.29	1.59	5.99	9.34	8.87	5.83	3.55	2.92	(0.20)	1.00	1.45	1.51	2.08	2.44	3.15	
Series : GDP growth (annual %)	6.10	6.40	3.50	2.40	3.20	4.10	4.50	6.80	7.10	7.10	7.20	4.70	5.10	1.80	2.20	2.20	2.90	4.40	4.30	4.20
Unemployment, youth total (% of total labor force ages 15-24) (modeled ILO estimate)	20.13	24.38	27.49	26.23	29.15	28.32	31.18	30.23	25.03	25.77	25.44	24.43	29.44	34.54	34.37	32.65	34.68	34.28	32.95	32.60
Share of youth not in education, employment or training, total (% of youth population)																	27.61	27.57	26.87	
Unemployment with basic education (% of total labor force with basic education)										2.98	3.86	2.94	8.62	9.89	9.89	11.54	8.97	8.54	6.84	
Unemployment with advanced education (% of total labor force with advanced education)										15.98	17.88	18.50	19.91	21.21	21.97	19.94	21.64	20.63	20.75	
Unemployment, total (% of total labor force) (national estimate)	7.95	8.98	9.26	10.01	11.01	10.32	11.20	10.49	8.80	8.52	9.09	8.76	11.85	12.60	13.15	13.10	13.05	12.41	11.74	11.43

Source: World Bank Open Data, UNDP

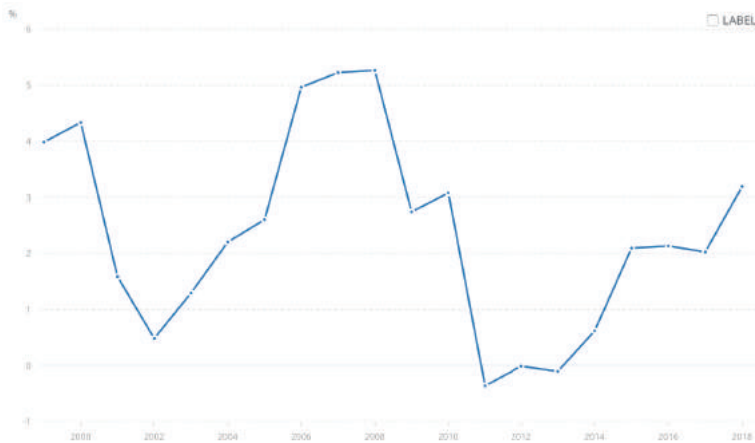


Figure 2: GDP per capita growth 1999–2019.

Source: World Bank

the EBRD, in 2016, the private sector made up 60% of Egypt's economy and employed 74% of the labor force.

Comparatively, HDI grew at a slower rate than GDP but increased steadily under Mubarak. This was disrupted by the revolution, leading to a stagnation of HDI in the few years following the crisis and increasing at an even slower rate under Sisi. The HDI rank declined by four places from 2016 to 2017. However, due to the nature of HDI, it is a better indicator for long term development that takes time to implement (such as health and education), so this should not be the sole assessment of development for the Sisi era. Infant mortality has fallen at a relatively steady rate given better healthcare and a falling birth rate throughout the country (UNDP 2019). Along with the steady increase in HDI, this shows consistent basic development. In contrast, the headcount ratio at the national poverty line has risen greatly over the past two decades and has not gotten better under Sisi (from the data that is available). Partially due to rapid liberalization and the creation of a business elite, there is an increasing number of poor in the country. Increased inequality also raises questions about how much of the economic growth is benefitting the people. With a falling population growth rate and high economic growth, the situation is especially worrying.

Education tells a unique story. Shown in Table 1, literacy rate was growing under Mubarak and reached its peak shortly before the revolution. The data collected during the Sisi era shows a decline once again, a reversal in development. Primary completion rate is even more telling. The overall increase under Mubarak to 100% shows progress in universal primary education.

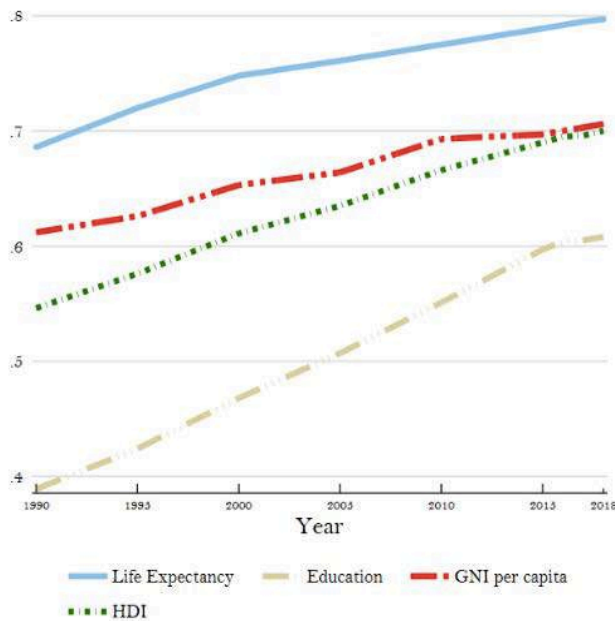


Figure 3.
Trends in Egypt's HDI component indices.

Source: UNDP

However, primary completion has fallen under Sisi like literacy rate, showing a lack of investment into education. The current education expenditure is not published officially.

The unemployment rate overall is not terrible for a developing country, but it does reflect the lack of economic opportunity many people face. Employment took its biggest hit after the revolution and has not recovered to pre-revolution levels, reflecting a slow recovery. Youth unemployment is a significant issue in Egypt, and arguably one of the factors that led to the revolution. Shown in Table 1, youth unemployment peaked around the time of the revolution and remained high after the revolution and under Sisi. This is still a fundamental issue that needs to be resolved along with high rates of unemployment among the highly educated. The well-educated middle class is not receiving enough opportunities, as shown by the contrast with the unemployment rate of those with basic education. A large share of youth not in education, training, or employment also brings into question the merits of the current system.

The picture of development in Egypt is depressing, especially considering the rather impressive rates of economic growth. Investment in education and health is crucial for successful long-term development since it is one of the

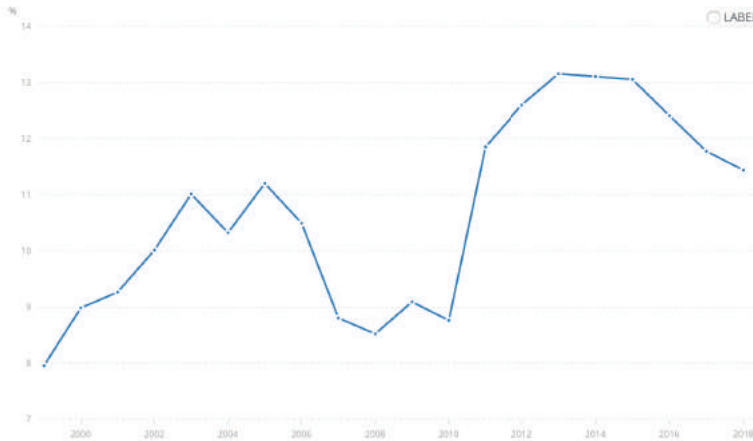


Figure 4.

Unemployment, total (% of total labor force) (modeled ILO estimate).

Source: World Bank

main weaknesses currently. It is hard to say whether development had been satisfactory under Mubarak or Sisi, but the general economic situation after the revolution has worsened and its recovery slow. Whether the military-dominated economy may bring the necessary development is in question.

2.1 Mubarak Era: A Vantage Point For Comparison

The Mubarak era can be split into three time periods: large infrastructure rehabilitation (1981–1990); economic reform (1990–2000); and neoliberal free-market economy, privatization, and deregulation (2001–2011) (Fahmy 2012). The Sadat free market led to millions of people without a safety net or access to public services (Fahmy 2012). Mubarak came to power on the promises of rehabilitating the failing infrastructure and holding office for a single term. Through huge amounts of foreign investment amounting to \$50 billion, Mubarak managed to build infrastructure projects that bettered the lives of most of the population (Fahmy 2012). The developmental policy was largely debt-financed and led to major problems in the following decade, although clever political actions including the Kuwait War led to the forgiveness of half the debt. With the disappearance of international debt and huge amounts of foreign aid brought by the United States, Egypt entered an era of rapid economic development.

During the 1990s, Egypt signed free-trade agreements with various countries, subscribing to the neo-liberal economic theory of development. A prominent example would be the “Qualified Industrial Zones” (QUIZ)

Agreement, whereby Egypt had special designated free trade zones that used Israeli imports to export to the United States—mainly textiles—free of tariffs (Zarzoso et. Al 2018). Various other multilateral and bilateral agreements were signed with Europe. Trade liberalization became a hallmark of the latter half of the Mubarak era and has a strong impact still today. Compared to Egypt under Nasser, with extremely high tariffs that tried to protect domestic manufacturers, Egypt under Mubarak joined the WTO in 1994 and signed many bi-lateral and multi-lateral trade agreements in the 1990s (Zarzoso et. Al 2018). Since then, it has shown a strong commitment to WTO rates and also pledged to decrease non-tariff trade restrictions, although it largely did not follow through. There are especially low tariffs on petroleum products, dairy, chemicals, and cotton, which are especially export heavy. Though manufacturing makes up a huge portion of the economy (17.1% in 2016 and 16.1% in 2010), many of its inputs are import-based and therefore heavily influenced by trade restrictions. The removal of both tariff and non-tariff measures can, therefore, increase the productivity of manufacturing firms (Zarzoso et al. 2018). It makes domestically unavailable inputs cheaper, decreases the price of intermediate goods, and also encourages technological transfers. Though trade liberalization brought higher growth rates, it actually also led to more cronyism, another piece of evidence showing that economic development was in the hands of the business elite.

In the 2000s, the development agenda had changed to deregulation and privatization, furthering the rapid rates of economic development that we see in the years leading up to the revolution (Bakr 2013). The government had a weaker presence in the economy, though there were still many large infrastructure projects that would drive economic growth and bring foreign direct investment. As detailed in the literature review, most scholars do not believe a lack of economic growth was the issue in the economy. There is wide consensus that crony capitalism, involving the political and business elite, was prevalent in the Mubarak era. Economic reform and liberalization throughout Mubarak's rule caused the wealthy to become richer and the situation of the poor to remain largely unchanged.

2.2 Expanding Corruption

The final decade of Mubarak's rule was characterized by rampant institutionalized corruption: crony capitalism. His son Gamal Mubarak and close associates managed to gain an unprecedented amount of wealth through the deregulation and privatization of state industries, buying cheap land, and the police. An infamous case would be the monopolization of the steel industry through privatization under Ahmed Ezz, one of Gamal's closest

associates. He managed to monopolize 65% of the steel market by acquiring shares of public enterprises through credit from the national banking sector (Fahmy 2012). As a leader of the ruling party, the National Democratic Party (NDP), he crafted anti-trust laws and in effect granted himself immunity to all further prosecution. As privatization sped up at the turn of the century, nation-wide poverty and inequality increased too, because most profits went to large business owners.

Mahmoud Abdel-Fadil, one of Egypt's most prominent economists, listed some of the corruption mechanisms exercised by the business elite to amass their wealth during this period (Abdel Fadil 2011): the use of privileged information to acquire an advantage in the privatization program and insider trading; acquiring liquid funds from the banking sector to buy shares and assets in the stock market, securing gains at no risk; allocating credit on the basis of personal contacts and relationships; the sale of public land at negligible prices and many times through "direct allocation" to select people in what became known as "the largest land grab" in the history of Egypt—taking into consideration that this land was subsequently resold for exponential multiples of its original price, making billions in very short time spans; illegitimate commissions made on arms deals and from sole-sourcing in the purchase of equipment and materials for public use; allocating billions in foreign aid funds received by Egypt primarily from the United States and the European Union in reward for its central role in preserving and advocating peace in the Middle East; and reallocating such aid funds to private firms and consultants (Fahmy 2012).

2.3 The Military Under Mubarak

The military played an important role during the Nasser and Sadat eras with development and industrial production. With privatization and trade liberalization the name of the game, state and military-owned enterprises shrunk in importance and market share in the Mubarak era. As shown in the figure below, military expenditure was brought down to about 2–3% of GDP for most of Mubarak's reign.

Other than foreign competition, Mubarak's strong support for the free market—that benefited the business elite—caused the decline of military enterprises. Added on top of the fact that military produced products are not widely liked in Egypt: Queen pasta, Safi mineral water, and Wataniyyah gas stations are examples (Magd 2011). The army forces soldiers to spend their salary on military-produced food products in remote areas where other brands are not sold (Magd 2011). Oppression in military factories and businesses has long been a concern in Egypt. Factory 99 has been associated

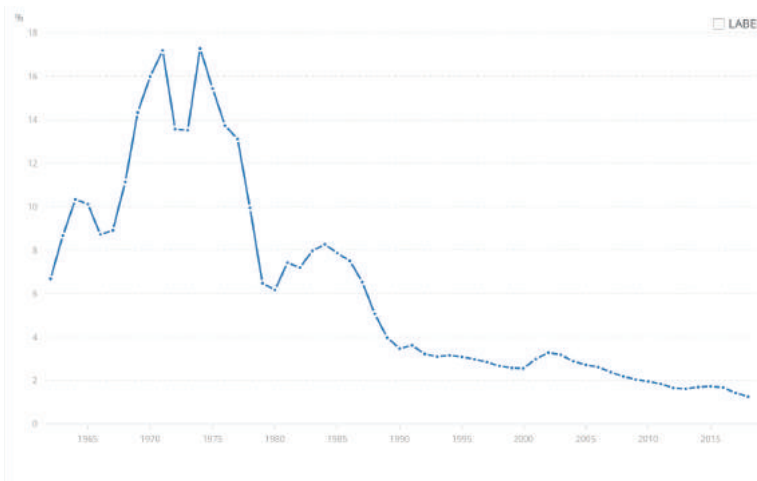


Figure 5.
Military Expenditure as Percentage of GDP.

Source: World Bank

with repression of workers because it is not subject to government regulation or union oversight. There is an infamous case where an explosion killed a worker, and the director responded that it was okay if one or two of them died. The following strike and protest resulted in leaders being tried in military courts for revealing “war secrets” (Magd 2011). There are many stories of conscripts being forced to work on livestock farming instead of receiving military training. With the military’s attention diverted towards economic activities, the ability for it to complete its professional duties is questionable.

As seen previously, businesses under the Ministry of Military Production and the Arab Organization for Industrialization (AOI) are actually largely oriented towards civilian products rather than military products. According to Zeinab Abud-Magd, 40% of the products manufactured by the Ministry of Military Production are actually non-military products. 70% of AOI products are geared towards civilians, even though it is the largest weapons manufacturer in Egypt. The National Service Products Organization (NSPO) manufactures only civilian goods, though receiving military privileges.

The level of political influence the EAF possesses is also one of the causes of corruption, leading to economic losses for the state. Of the 156 governors appointed under Mubarak, 68 were from the armed forces. 203 generals were found to occupy undersecretary, general director, and other bureaucratic positions. An estimated 2000 posts in local governments were occupied by former military officers (Nassif 2013). Generals of the Navy were mainly appointed to the Suez Canal and head of ports, while air force generals were

given control over airports. Massive corruption has plagued this extensive system of control.

Major General Sa'd Khalil, former governor of Matruh, underpriced 1659 acres of public land in El'Alamein on Egypt's northern coast. The deal cost the treasury more than \$167 million (Nassif 2013). Similarly, Major Samir Farag, former governor of Luxor, was arrested for selling an Olympic stadium for \$7.3 million when the market price was \$58 million (Magd 2011). The generals have also consumed parts of the state budget designated for disaster management and other security-related activities. This money was given directly to generals as "loyalty allowances," reaching \$2.75 billion, almost 9% of the GDP in 2005/2006 (Nassif 2013). There has also been evidence of generals taking cuts from arms deals with western companies. The \$1.5 billion annual U.S. military aid used to purchase weapons was used at the discretion of the military, so millions of dollars were taken away to off shore bank accounts as a result of corruption that favored certain companies.

Overall, the military has a minor role in the economy in terms of volume. High levels of corruption and an extensive focus on civilian products creates a worrying situation regarding the ability of the EAF to perform its professional duties. The top brass has amounted strong political influence over the country through complex systems of gaining rewards. The traditions left by Nasser and Sadat have continued for political survivability. At the same time, the military elite benefit from the business ventures, expanding their activities through cheap labor provided by soldiers, tax exemptions, and control over public land. All of this paints a worrying picture of how the military may influence the economy. An expansion of such a spoil-dividing, corrupt system will lead to a major waste of resources. The neo-liberal stance of the Mubarak regime has definitely exacerbated the situation leaving the question of how to manage military businesses to Sisi, who is one of the benefactors of this system.

2.4 Military Businesses Under Sisi

The problems caused by the military under the Mubarak regime have continued and are even more obscure after the ascension of former general Abdul Fattah el-Sisi. Local Egyptians have talked about freedom of speech becoming limited under the new regime. Criticizing the military can often lead to severe consequences like imprisonment. It has become harder to see the political deals behind the scenes.

The military restored economic stability and initiated a revival of the troubled economy after the revolution and Morsi. The merits of the new regime's economic development are widely debated. This paper will suggest

that excessive military intervention in the economy, especially when it destroys competition, has a negative impact. Examining the effects of the military through its visible actions is one way of determining the problems with current military-based institutions and their implications for economic development. When the military supported Morsi's removal in 2013, it expanded its power further. The election of 2014, staged by the interim government, ended in former Defense Minister and General Abdel Fattah El-Sisi's victory. Attempts by the civilian Morsi government to reign in military spending and improve the accountability of military economic actions had failed.

Three institutions which govern businesses are directly owned by the military: the Ministry of Defense, the Ministry of Military Production, and the Arab Organization for Industrialization. The Ministry of Military Production oversees 20 businesses, the Ministry of Defense oversees a dozen, and the Arab Organization for Industrialization oversees at least 12. The Ministry of Military Production projected its operating revenues would increase to reach 15 billion Egyptian pounds in 2018/2019, 15 times 2013/2014 (Reuters 2018). Military owned businesses have been estimated to take up 25%-45% of the economy, while Sisi said in a public statement that it was only 5% and wished more could be owned by the "efficient" military (Magd 2011; Harding 2016).

The military has a wide scope of business interests that range from construction to fish farms to holiday resorts. Examples include El Arish Cement Co., which recently built the largest cement plant south of Cairo, which took \$1 billion, 18 months, and 8000 workers. The full capacity of the plant is 12.6 million tons of cement each year (Mandour 2019). Commercial ventures alone may not be bad. However, questions have been raised about the feasibility of such a large plant. The annual national production of cement was 79 million tons in 2017, with only 52 million tons of consumption (Reuters 2018). The motive for such expansion is questionable, and this is a prime example of the potential harm of excessive intervention.

Currently, the EAF still does not need to pay taxes and does not have oversight of its various ventures. The budget and revenue are off the books, but in 2012, Major General Mahmoud Nasr divulged the annual revenue of the military's businesses (\$198 million) and its take of the state budget (4.2 percent) (Marshall 2015). How much of the military budget is used to subsidize its enterprises is unknown. According to Nassif, the whole system of military enterprises operates outside the control of both parliament and the Organization of Administrative Monitoring, which is also dominated by retired generals. Officers are not accountable for the income streams generated by the armed forces' economic activities because the related information is considered to be "military secrets."

Unfair competition arose from the cuts in fuel subsidies by the civilian government that did not impact the EAF, whose fuel is still subsidized by its budget. In 2016, the military businesses were exempt from the new value-added taxes (VAT) that were recommended by the IMF. The military does not need to pay VAT on goods, equipment, raw materials, etc., on the grounds of national security (Reuters 2018). These existing policies benefit companies directly owned by the military and gives them an unfair advantage in competing with civilian private businesses.

Egypt's ease of doing business ranking remained virtually unchanged over the period after Mubarak, ranking 112th out of 189 countries in World Bank's 2015 annual *Doing Business* report, published fifteen months after General al-Sisi seized power. Its lowest performance, 152nd place, was on the key indicator of 'enforcing contracts', reflecting—at best—stagnation of the vital legal/judicial system and overall weakness of the rule of law (Springborg 2017).

All of this brings into question not only how unfair competition will affect the private sector of the economy, but also how well the military may complete its primary objectives (Springborg 2011). Recent cases of terrorists being able to kill soldiers stationed in Sinai for security exemplify this problem. With the military so focused on commercial ventures and political issues, there is a lack of training and effective organization towards maintaining security. Corrupt arms deals explained later also signify that the military is not first considering how to protect the country, but rather how to make a profit. It is very hard to measure how much the private sector is suffering from expanded operations of the military at an unfair advantage. The weaknesses in institutions, government or military, throughout this paper will reveal a part of the story.

2.5 Cases Of State Projects And Development

Poor planning, poor management, and the excesses of the current government are exemplified by the Suez Canal project, a new capital city in the middle of the desert, and dramatically increasing funds for "Toshka," a multi-decade land reclamation program. Other prestige projects have been announced recently, including the tallest building in Africa, the Largest Museum in the World, and suspension bridges. Mega-projects are meant to attract foreign investment and buttress the grand ambitions of providing jobs and reviving the economy while keeping the military happy with construction contracts. These huge projects echo the excesses of Mubarak in prestige projects and rampant crony behavior.

During the Mubarak era, multiple cities were established in the desert close to Cairo in an attempt to relieve some strain from the city of 9 million,

but in reality, none have thrived as expected. The most notable example is New Cairo, a city established in 2000 that was designed to host a population of 5 million people. It ended up having a fraction of the planned residents and was subject to mass corruption and real-estate speculation (Deknatel 2019). History seems to be repeating itself with the establishment of the new unnamed capital city. Even before the city is being built, roads leading to it are paved by the military (Barnes 2018). Ahmed Zaki Abdeen is the retired general who runs Arab Contractors, a local construction company that is building the new capital city. He expresses his concern that the state is not providing the necessary funds for development. The Chinese State Construction Engineering Corporation pulled out over disagreements with the housing ministry about price in 2017 (Barnes 2018). Despite delays, the government has been optimistic. The administrative buildings are projected to cost \$45 billion (Reuters 2018). Although the development of the new capital city resembles Mubarak era ambitions, the military and its affiliates are taking a large share of the benefits from the construction process, instead of the private sector.

Another noteworthy example of super construction is the expansion of the Suez Canal. The EAF was granted commissioning rights, the only entity that could deal out contracts for the canal's construction (Marshall 2015). The military also has a strong influence over the Suez Canal Authority, which is now headed by a retired general. The construction of the newly expanded canal cost \$8 billion, mainly financed by local bonds. Questions have been raised about the motive for expansion, especially with the unstable nature of global trade. Former chairman Lt. Gen. Mohab Mamish said that revenue was projected to be \$13.4 billion in 2023 (Hellenic Shipping 2017). However, the revenue barely changed in the three years following the expansion, and even fell for some years. Revenue was \$5.5 billion in FY 2014 at a 6% growth rate. After the expansion, it was at \$5.2 billion in FY 2015 and \$5.0 billion in FY 2016. Revenue finally returned to its pre-expansion level of \$5.5 billion in FY 2017 and increased slightly to \$5.8 billion in FY 2018 (Elhamy and Davison 2018; Egypt Today 2019). The assumption of growth was based on the expansion of global trade, which is not a stable factor. The EAF's Engineering Corps built most of the canal and completed the extension portion in just under one year. President Sisi claimed that this level of efficiency could not be achieved by the private sector. Overall, the benefit of the canal is nowhere near the projected value, and this has been a questionable investment along with major military-affiliated contracts and interests

Other examples of questionable investments include a non-competitive contract of \$40 billion for a low-income housing project awarded to Dubai-based developer Arabtec Construction. The government claimed that it

would provide a necessary stimulus. News sources also reported that part of the state-owned shares of the profitable telecom company Vodafone Egypt is being transferred to the military intelligence departments (Atallah 2014). The military is extending its throughout different industries and has interests in major state projects.

Meanwhile, there is a lack of basic development of critical infrastructure, such as public transportation, healthcare, and education. The problems are especially visible in transportation. For example, the railroad system needs significant maintenance that may cost up to \$208 million; however, only \$18 million was allocated (Shamma 2018). There was a 33% increase in accidents in 2017 to 1657 accidents. The rise in the poverty rate from 27.8% to 30.2%, despite high levels of economic growth, reflects that there is still a lot of development to be done. Investment in human capital, not so glorious infrastructure, and basic services are critical to sustainable development in Egypt.

2.6 Military Power In Politics And Its Rewards

A heightened level of political participation by military interests is worrying because it reflects an increased ability to impose military interest onto the state. The simple ability of the military to oust any civilian government it doesn't like puts a huge amount of power in the hands of the military. During the Morsi era, the government was forced to make concessions on multiple fronts in order to satisfy military interests. For example, when Morsi announced that Indian contractors were to build the Suez Canal, a military spokesman declared that there would be no construction unless it was approved by the EAF. The official also insisted that the EAF required sole jurisdiction over the court in cases that involved disputes with commercial and industrial projects, and stricter laws for foreign companies. Tarek Wafiq, the housing minister under Morsi, responded by agreeing to show the military plans of the project but refusing to make any alterations. Three months later, he declared that the military would be the sole entity to grant licenses for the Suez Canal (al-Najjar 2013). This level of power over state projects is worrying even without a former general in place as president.

In 2014, the interim government expanded the ability for ministers to sign no-bid contracts (Gamal El-Din 2014). "During just the first ten months under the interim government, the military landed nearly \$770 million in contracts, and over \$1 billion in no-bid government contracts over the course of three months in fall 2014" (Marshall 2015). Another prime example of military power is the passage of Law 32, which bans third parties from challenging the terms of public contracts (Adly 2014). This means only the government and those with legal standing may

go to court with deals. Ordinary private companies would therefore not be able to compete for below-market valuation of state assets and such croncy activities. Often these actions are hidden from public view by the lack of transparency within the government that has continued from the Mubarak years. The EAF has had a growing control over the economy and the political system since the government led by former defense minister Abdel Fattah el-Sisi came into power. The power of signing more contracts without bidding channels public funds towards military-owned businesses and military partners. This kind of expansion in power is understandably harmful to the economy because it blocks competition for state projects and disproportionately benefits military-owned firms.

Furthermore, the military has used the lapse in power to contract large foreign arms deals and also manages almost all of the foreign and military aid provided by the Gulf countries and the United States. While there were protests against Mubarak, a \$1.3 billion M1A1 coproduction deal was signed. It also promised to build six patrol boats for Turkey at its shipyard in Alexandria (Marshall 2015). These contracts, along with others, led to an expanding role of the military in domestic armaments and also export to middle eastern countries. Taking advantage of political power to further its own economic interests has been an increasingly obvious trend. Having so much power in civilian governments will lead to the military imposing its own interest on top of state interests, potentially harming the national economy.

2.7 Security

The military is the only security force left in Egypt since the police were greatly weakened by the departure of Mubarak. The police were a political tool that was heavily controlled by Mubarak personally. The withdrawal of the police during the Revolution of 2011 caused a security vacuum that the military and military police had to fill. Police presence was not truly established again until 2014, after Sisi was elected.

To have a secure business in Egypt, protection by the military and the stability it promises are necessary. In such an environment, investment fell in most sectors and was mainly awarded to military-affiliated businesses. The U.S. government's Overseas Private Investment Corporation continued to extend loans in 2011 during the height of the revolution to Citadel Capital, a firm chaired by a retired general (Marshall 2015). Businesses that were affiliated with the Mubarak regime and the Muslim Brotherhood, on the contrary, failed to secure investments. After Mubarak's fall, there was much focus on prosecuting business cronies and taking away their businesses (Marshall 2015). The Muslim Brotherhood affiliated businesses endured a

similar fate after the military assumed power since the Brotherhood was once again branded a terrorist organization.

During the late part of Morsi's rule, the military consistently ignored security regarding Muslim Brotherhood businesses, key facilities, and Morsi's personal safety. This was seen as an attempt to take down the Muslim Brotherhood government, but at the same time, it shows how crucial the military is to the security and stability of the country. When demonstrations against Morsi started, the military recalled its forces from key areas like public hospitals, which caused looting and strikes of healthcare personnel (Marshall 2015). These were all perceived as failures by Morsi to maintain stability.

There is also an inclination for the military to protect its own investment partners' interests rather than those of others. The military provided armed personnel to escort and protect the Kharafi group, according to company records. It was also generally quick to intervene in strikes that compromised its own interests. Comparatively little had been done about strikes in Port Said and Ain Sukhna, where strikes forced facilities to shut down and caused shipping to be re-routed to other countries. When negotiated terms with union leaders were violated after Morsi's removal, the military was sent in to break up strikes and even unloaded ships themselves. Such stark contrasts show the important role of the military in protecting business and keeping order in the country. Other cases include breaking up strikes at Cairo Airport, where the chief executives are former military officers, and the Suez, where there are multinational manufacturing and export interests (Marshall 2015).

Having this high level of influence over security and stability in Egypt, the military may wield this power to its own advantage, harming direct competitors with military-affiliated businesses. The military has proved in the past that it can do this, so it remains a potential pitfall to a stable environment for production and economic growth.

3.1 Conclusion

Mubarak had an approach to economic development through massive liberalization and privatization, so consequently, the military was in a relatively weak economic position. Comparatively, the military has significantly increased its role in the Egyptian economy during the Sisi era. Economic growth in nominal measures has increased slightly through investment in large scale projects designed by the leadership. There is no quantifiable measurement or a clear picture of how much the military affects the economy, but as shown through various sources, the influence has definitely expanded compared to the Mubarak era.

Crony capitalism took away the majority of the benefits created through development under Mubarak. This can be seen as the majority of the people became poorer and the middle class eroded. An extremely small percentage of the rich became extremely rich. In this case, such huge inequality is created by extractive institutions. These institutional problems have persisted, reflected by how easily the military can gain rewards from the system. Corruption is extremely prevalent, both under Mubarak and Sisi. The government (excluding the leadership) has been partially derelict in satisfying its duties in development and providing public services, so the military has since filled this role under Sisi by expanding its operations (military-owned and affiliated businesses).

Since Sisi came into power, the approach to development shifted more from the private sector to the public sector, especially since the military-dominated businesses expanded in operations. Though cooperation with the private sector is present, development is state-directed. Large infrastructure glory projects have once again taken center stage, much like the earlier Mubarak years. These projects take away funds from areas in dire need of improvement like public services, including healthcare and education. Sisi claims these super projects will satisfy the need for more jobs, but current economic data shows that the mismatch between capabilities and opportunities still needs to be resolved.

Given the track record of the military, it is hard to say that development has taken a turn for the better under Sisi. The massive corruption of both political and economic systems in giving out rewards to former military elite causes major losses to the state monetarily. Also, it puts personnel without governing expertise in crucial positions, hindering overall progress. The military, on the other hand, may fail at completing its own professional role: protecting the country. With security and stability in the hands of the military rather than civilian entities, businesses are forced to comply with certain standards. It is hard to be certain that the military will not use this to its advantage.

Beyond the problems with political corruption, military-affiliated businesses enjoy many unfair advantages over private businesses. Subsidies, tax exemptions, and other unjustifiable benefits weaken competition and may hinder growth. The military has shown its will in intervening in the market, including directly giving out state contracts and favoring certain companies over others. It is not easy to do business and contracts are not well enforced even after Sisi's efforts to improve the situation.

The military seems to be an important party behind the slow resolution of major challenges to development in Egypt. Two of the most important issues are institutional reform and investment in basic public services. As

shown throughout the paper, the military may very well be the inhibitor of institutional reform because of the massive benefits it reaps from the current system. The military's interactions with the political system remain corrupt and unchanged from the previous era. Also, Sisi is promoting large infrastructure projects rather than focusing on improving basic services. It has been shown that the military has a large stake in such prestige projects through construction. The military possesses a greater influence than before and is positioning itself to protect its own interest rather than encouraging development throughout the country.

Taken overall, expanded military control has huge potential to bring negative long-term consequences despite short-term economic growth. The major concerns include continual political corruption, stifling of competition, mismanagement of public resources, and inhibition of institutional reform.

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Computational Fluid Dynamics Pilot Prediction Model of Vulnerable Plaque in the Femoral Artery

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Abstract

PAD is a widespread disease commonly caused by atherosclerosis. It mostly affects the legs and, in particular, the femoral artery. According to previous research, atherosclerotic plaque develops and ruptures at specific sites of the stenosis. It has been suggested that a particular distribution of wall shear stress has contributed to the progression or lesion of vulnerable plaque. The purpose of this study is to build a CFD model to simulate and predict the risks of atherosclerosis in the femoral artery. The geometries were obtained from CT scan images of a patient and four segmentations were created to mimic a gradual blockage of the femoral lumen by a ring-like plaque. WSS values along the stenosis were categorized into four severity levels, with each level linked to a different possibility of plaque formation or rupture. Therefore, this study promotes a new pilot prediction system that integrates WSS values on a risk assessment scale. This could provide a highly personalized way of examining the stage of PAD in the femoral artery and enable doctors to carry out timely treatment for atherosclerotic plaque.

Keywords: peripheral artery disease; atherosclerosis; atherogenesis; vulnerable plaque; plaque rupture; femoral artery; computational fluid dynamics; hemodynamics; wall shear stress

1. Introduction

Peripheral artery disease (PAD) is the preferred term for the partial or complete obstruction of one or more peripheral arteries.¹ It often affects the legs, and the most common symptoms include intermittent claudication, which is leg pain associated with walking and relieved by rest.⁴ Moreover, as the global population ages, PAD may become even more prevalent.⁴ Despite its increasing threat to global health, PAD may be underdiagnosed, undertreated, and poorly understood.

Atherosclerosis is by far the most predominant cause of PAD.² Atherosclerotic plaque can be characterized as either stable or vulnerable, depending on their structural composition. Stable plaque contributes more to outward vessel remodeling and preserves the lumen,³⁷ while vulnerable plaque encroaches on the lumen, reducing blood flow as well as vascular reactivity of the large arteries.^{35,36} Most importantly, vulnerable plaque may be prone to rupture and cause thrombotic or embolic complications, such as ischemic stroke and myocardial infarction.³

Previous studies have reviewed the relationship between several parameters, such as plaque geometry,³⁸ plaque composition,²⁷ and shear stress with plaque progression and rupture.³² Magnetic resonance imaging (MRI) findings show that local blood flow characteristics, particularly wall shear stress (WSS), may contribute to the development and rupture of atherosclerotic plaque in PAD patients.¹⁰ Low WSS leads to atherogenesis by altering cholesterol transport and high WSS induces plaque rupture by stimulating the endothelium to reduce the thickness of the plaque's fibrous cap.^{11,26} Within an artery, plaque rupture tends to occur upstream of the stenosis with high WSS, while formation of more atherosclerotic plaque mostly happens at the post-stenosis region with low WSS.¹² Therefore, WSS could become a potential parameter in techniques to identify the stage of atherosclerotic progression and to predict of possibility of plaque rupture.

There are plenty of computational models of blood flow in the carotid artery, the coronary artery, and the aortic arch, where plaque may be more commonly observed. However, there is a limited amount of literature on plaque formation and rupture in the femoral artery. P. Assemat et al.⁸ discovered that the presence of plaque could alter blood flow and WSS distribution in mice's aortic arches, with regions of high WSS mostly observed where luminal narrowing is most obvious. A similar simulation was carried out based on human arteries. A. Roodhouse⁵ created several computational models in the femoral artery and found that WSS before and after the stenosis is greatly reduced because the stenosis directs the majority of the flow towards the center of the artery, lowering the flow close to the vascular wall.

As flow is directed away from the wall, the chance of building up atherosclerotic plaque increases. Liu and D. Tang⁷ also investigated the influences of WSS, blood viscosity, and the inlet flow rate on atherogenesis in a three-dimensional model of the coronary artery. They found that WSS peaks at the neck of stenosis and reaches its minimum value at the post-stenosis region. Moreover, the more severe the stenosis, the greater the range of WSS. Liu and Tang also stated that the low, post-stenosis WSS may promote downstream expansion of plaque.

What's more, current results of computational models do not prioritize easy interpretation for physicians and patients²⁵, highlighting the need to create a readily understood risk assessment model for doctors and patients. Computational fluid dynamics (CFD) simulation is a non-invasive, efficient, and flexible method to present the detailed, three-dimensional flow field in blood vessels, which has the potential to replace *in vivo* strategies⁶. Compared to other non-invasive methods, such as ultrasound, CFD could give out a clear presentation of the direction and velocity of blood flow. Since a special pattern of WSS distribution was observed in other arteries, the femoral artery might have a similar WSS distribution. Therefore, the purpose of this study is to create a patient-specific, three-dimensional model to simulate atherogenesis in the superficial femoral artery (SFA). Based on real-life computed tomography (CT) scan images, detailed local hemodynamic distribution can be obtained and investigated. By monitoring wall shear stress along the plaque, this study sets up a pilot prediction system for plaque formation and rupture, which could help to determine irregularities in blood flow for both healthy individuals and PAD patients. Even though no calculations are being made immediately, the CFD model could be adapted for later simulations in the femoral artery. Detection and analysis the progression of femoral artery atherosclerosis enables early diagnosis and intervention to prevent functional declines and fatal complications, which may severely impair patients' quality of life.⁹

2. Methods

2.1 Geometric Model

In this section, the process of constructing a three-dimensional computational model of the left femoral artery from pelvis computed tomography (CT) images will be discussed. Firstly, a series of CT images (Figure 1) of the pelvis was obtained from the Cancer Genome Atlas Sarcoma (TCGA-SARC) data collection via the Cancer Imaging Archive website.¹⁷ The images were taken in DICOM format on Aug 3, 1998, and details of the patient

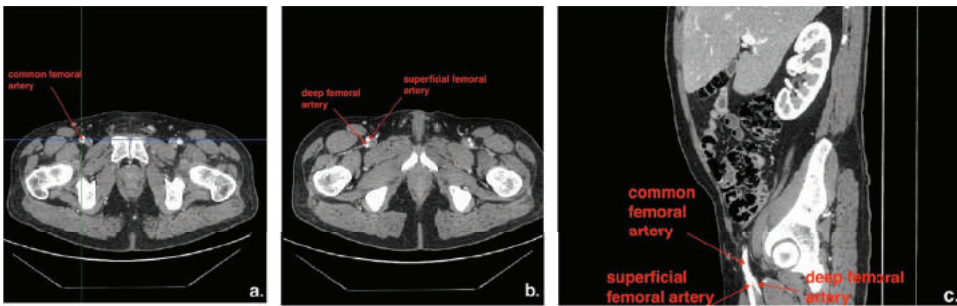


Figure 1.

CT scan images showing the geometry of the femoral arteries modeled in this study. The images are of the size 512 x 512 pixels per slice and each pixel represents a $0.79 \times 0.79 \text{ mm}^2$ area. Resolution is 0.63 in the axial direction, 0.88 in sagittal, and 0.88 in coronal. (a) axial view of CFA (b) axial view of SFA and DFA (c) sagittal view of CFA, SFA, and DFA

were removed. Consisting of a total of 1,913 CT scan images, this series of sequentially-taken CT images provides a detailed presentation of the arteries in the lower limbs with good contrast. In my experiment, 72 slices (53.12 mm of the femoral artery with bifurcation) were selected, with a slice increment of 0.63 mm. The images were inspected and processed using the computer software SimVascular, which allows for relatively detailed segmentation and the creation of a 3D model of the common femoral artery (CFA), femoral bifurcation, superficial femoral artery (SFA), and deep femoral artery (DFA).

Next, two centerlines were generated in the software SimVascular. The first starts from the inlet cap of CFA, continues through the bifurcation along the SFA and ends at its outlet cap. The second starts from the bifurcation, runs through the DFA and ends at its outlet cap. Fourteen center points were identified in each centerline. Then, segmentation of the CFA, DFA, and SFA was carried out to construct three-dimensional images of the femoral bifurcation from axial images of the arteries. The images selected have a good contrast: the blood vessel wall is displayed in a bright white color while the lumen and surrounding tissue are in dark grey or black. Thus, the inner vessel wall was segmented along the outermost white pixels, as shown in Figure 2. However, it could still be difficult to separate the SFA and DFA because both vessels have smaller branches after bifurcation from CFA. Therefore, given that the aim was to simulate plaque progression in the main branch of SFA, smaller branches of SFA and DFA were identified and intentionally ignored to create a model consisting of only the main branches of the two arteries, as shown in Figure 3.

In order to create four models of varying percentages of blockage areas to simulate the progression of femoral plaque, four distinct contour groups

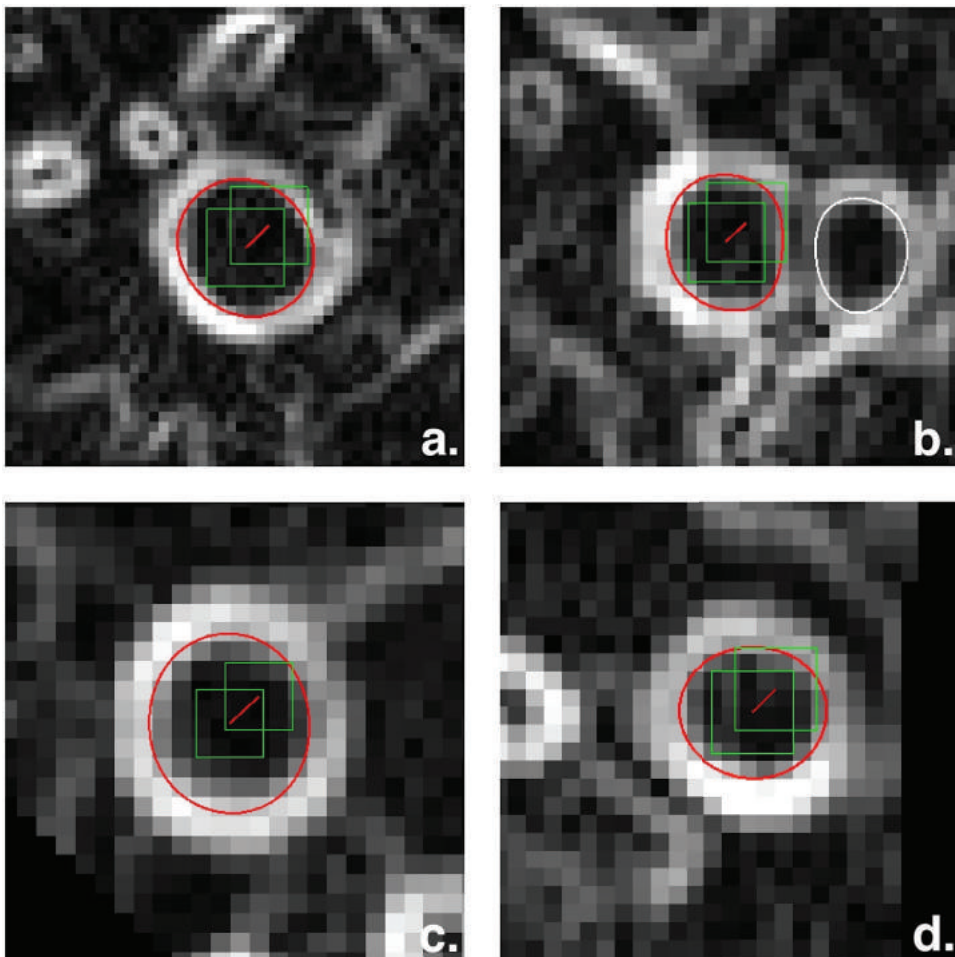


Figure 2.

*Views of segmentations at different locations along the femoral artery.
 (a) CFA at the inlet (b) bifurcation of CFA into healthy SFA (red circle) and
 DFA (white circle) (c) healthy SFA at the outlet (d) DFA at the outlet*

were created with varying thickness of plaque. According to real medical images of plaque in SFA (Figure 4), the plaque is formed on the inner arterial wall as a ring and the thickness of the ring gradually increases according to increased severity of atherosclerosis.

Therefore, the lumen of the vessel was taken as a standard circle and four grades of severity of femoral plaque were created: 60% of cross-sectional area is blocked, 40%, 20%, and 0%, representing a healthy SFA as a control group. According to $A = \pi(R^2 - r^2)$, where A represents the cross-sectional area of the ring-like plaque, R the radius of the original blood vessel, and r the

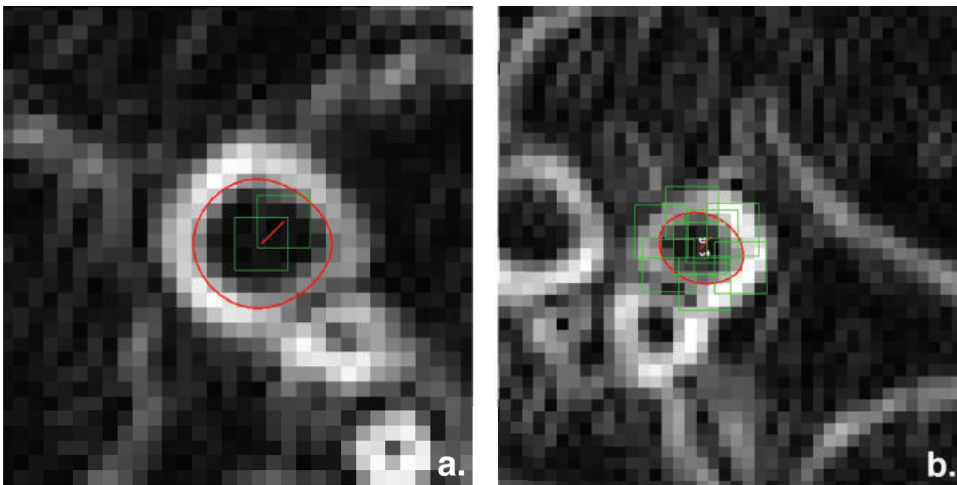


Figure 3.

An example of segmentation to single out the main branches of SFA and DFA. (a) main branch of SFA (b) main branch of DFA

blocked, the approximately circular lumen's radius should decrease by 37%, 23%, and 11%, respectively. It was difficult to measure the radius of the circle accurately on screen, so a pixel-calibrated scale was used. By artificially counting the number of pixels of the healthy radius, the radii of three atherosclerotic lumen were estimated respectively in number of pixels. Following this methodology, four different segmentations were created (Figure 5) to simulate the gradual progression of plaque characterized by increases in the ring's thickness and decreases in the lumen's radius. As shown in Figure 6, contoured slices were adjusted to an appropriate number so that they were neither too close for slices to overlap with each other, nor so far so that the models lacked too much detail. The minimum distance between contours is 2.52 mm and the maximum is 11.34 mm.

After segmentation, a three-dimensional computational model of the femoral arteries was constructed, as shown in Figure 7. The overall length of the model is 54.37 mm, with a total of 87 slices. Within the model, the length of CFA-SFA is 53.12 mm and the length of DFA, which starts from the bifurcation point, is 45 mm. The average diameter of the modeled CFA is 8.19 mm and that of the modeled DFA is 4.86 mm. Grades 0, 1, 2, and 3 SFA have diameters of 5.62 mm, 4.99 mm, 4.26 mm, and 3.63 mm, respectively.

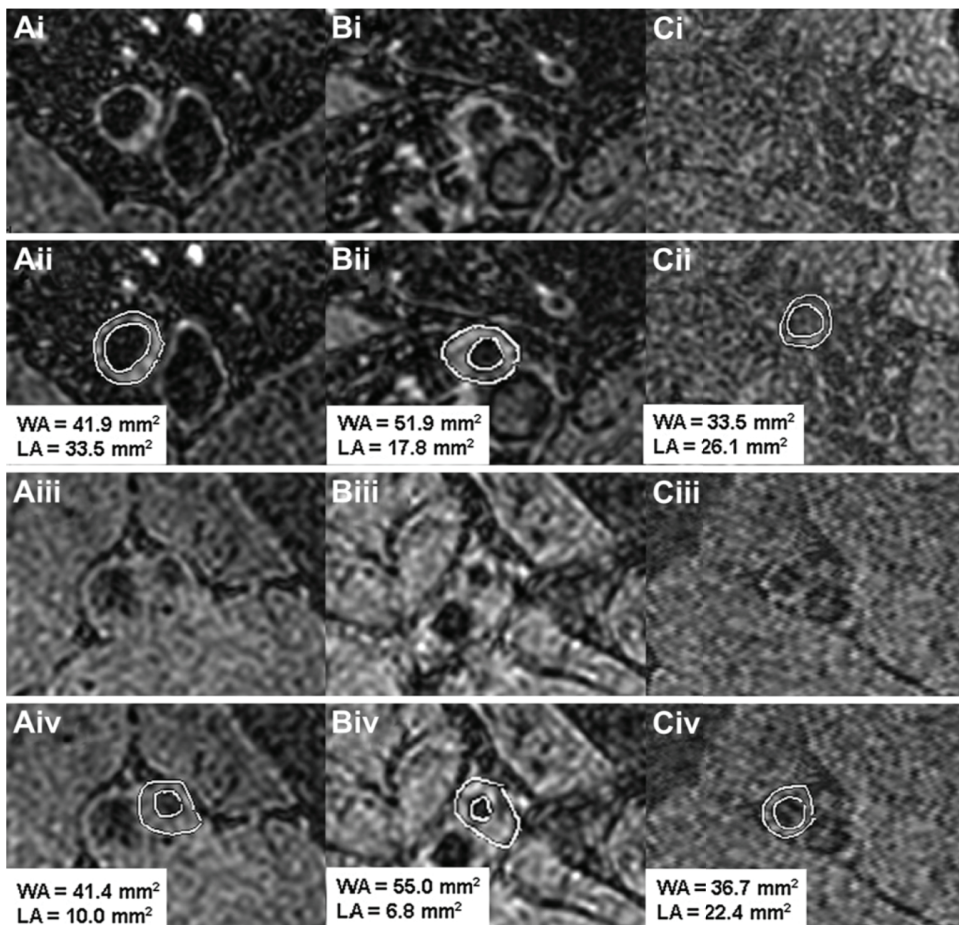


Figure 4.

Transverse images at the femoral bifurcation and adductor canal of three different patients. Each column represents images for one patient (denoted as patient A, B, and C). Rows i and ii show the same image selected from bifurcation with and without lumen boundaries, respectively. Rows iii and iv show the same image chosen in the adductor canal with and without lumen boundaries, respectively. WA is wall area and LA is lumen area. Figure reproduced from figure 3 in <14>

2.2 Boundary Conditions

Suitable boundary conditions are required for a fluid dynamic model. In this study, the boundary conditions consist of a no-slip wall, a constant flow rate at the inlet, equal to the mean flow rate in the femoral artery ($152 \pm 10 \text{ mL/min}^{13}$), and a zero-pressure condition for both of the femoral outlets. An average flow rate is used because of the Windkessel effect, which states that arteries have an elastic behavior that helps maintain a continuous flow despite the pulsatile

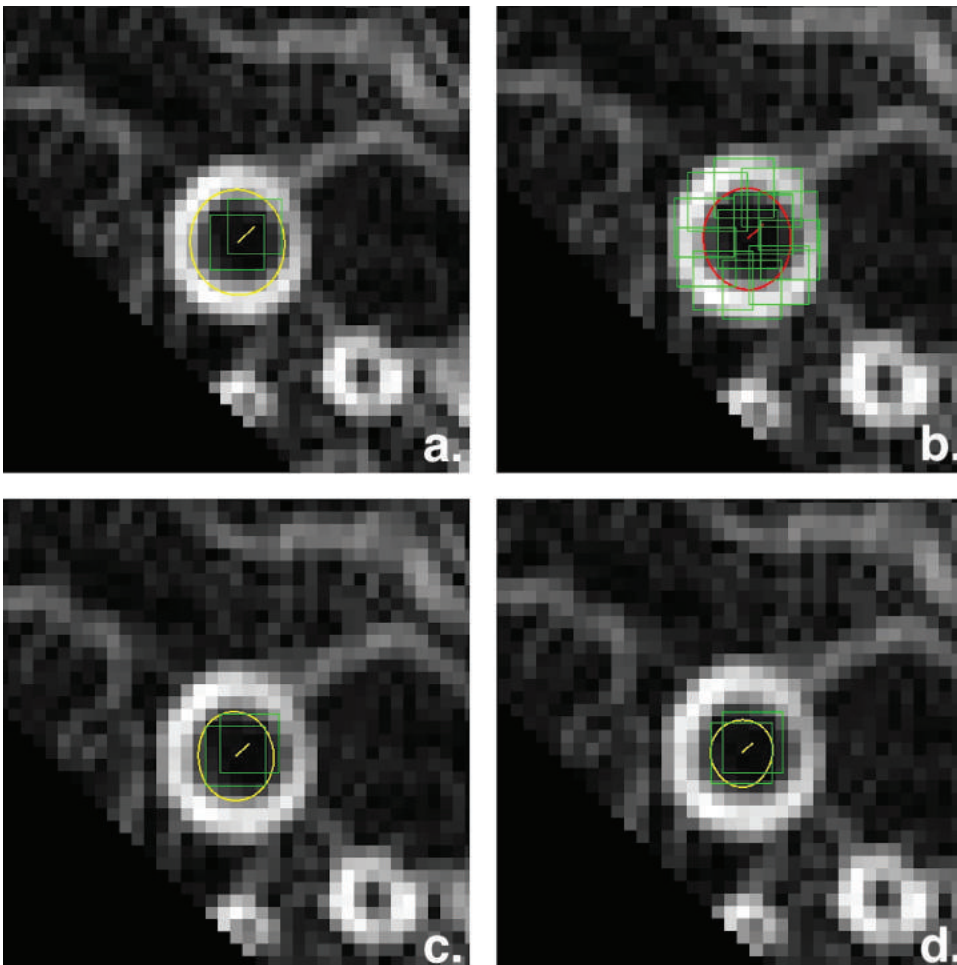


Figure 5.

Comparison of segmentations for different severity grades. (a) Grade 0: 0% of the lumen is blocked (b) Grade 1: 20% blocked (c) Grade 2: 40% blocked (d) Grade 3: 60% blocked

pumping of the heart.¹⁸ These boundary conditions were applied to all models for flow analysis.

2.3 Simulation of Blood Flow in Constructed Artery

SimVascular is useful for generating a tetrahedral mesh for the designed femoral models. Considering the purpose of this study, the mesh should be fine enough to allow flow field analysis and, at the same time, should be programmable for the SimVascular software. The number of elements of the entire model ranges from 186,024 to 1,717,958 in previous simulations of the aorta.^{19,20} About one million tetrahedral elements were used in a 10 cm-long

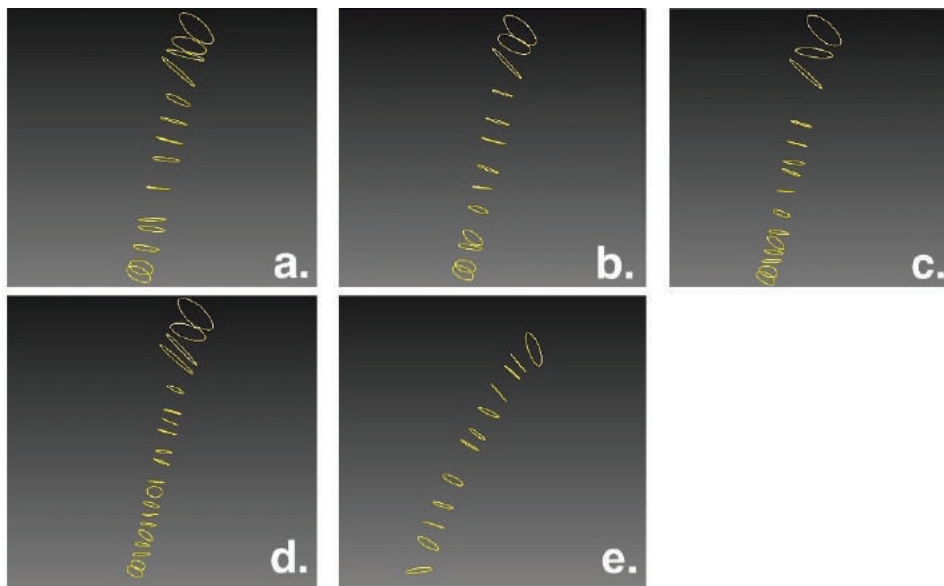


Figure 6.

Overall views of segmentations of different models. The luminal diameter of CFA remains constant while that of SFA is different for different severity grades. (a) CFA & Grade 0 SFA (b) CFA & Grade 1 SFA (c) CFA & Grade 2 SFA (d) CFA & Grade 3 SFA (e) DFA

model of a carotid bifurcation.²¹ Most importantly, in a past simulation of a 6cm long femoral bifurcation model, the mesh has 367,315 tetrahedral elements that covers the inside of the femoral artery and 18,695 triangles on the common interface.²⁵ Given that the model in this study is similar to the former in length and geometry, the number of elements can be used for reference. Therefore, with different estimated global maximum edge sizes, the mesh of DFA consists of 107,791 elements: 213,540 for Grade 0 SFA, 210,039 for Grade 1, 221,059 for Grade 2, and 227,504 for Grade 3. An example of the tetrahedral mesh is provided in Figure 8. Some assumptions are made in order to develop the model and simulation. All arteries' walls are stiff and inelastic. Additionally, blood is an incompressible Newtonian fluid while the flow has constant density and velocity.

3. Results and Discussions

In this section, results values of WSS along the plaque are categorized and related to different possibilities of atherogenesis and plaque rupture. In an attempt to provide the physicians and patients with a clear and easy way of interpreting a personal CFD simulation, results in WSS should be presented in a user-friendly, readily visualized format. Therefore, instead of presenting

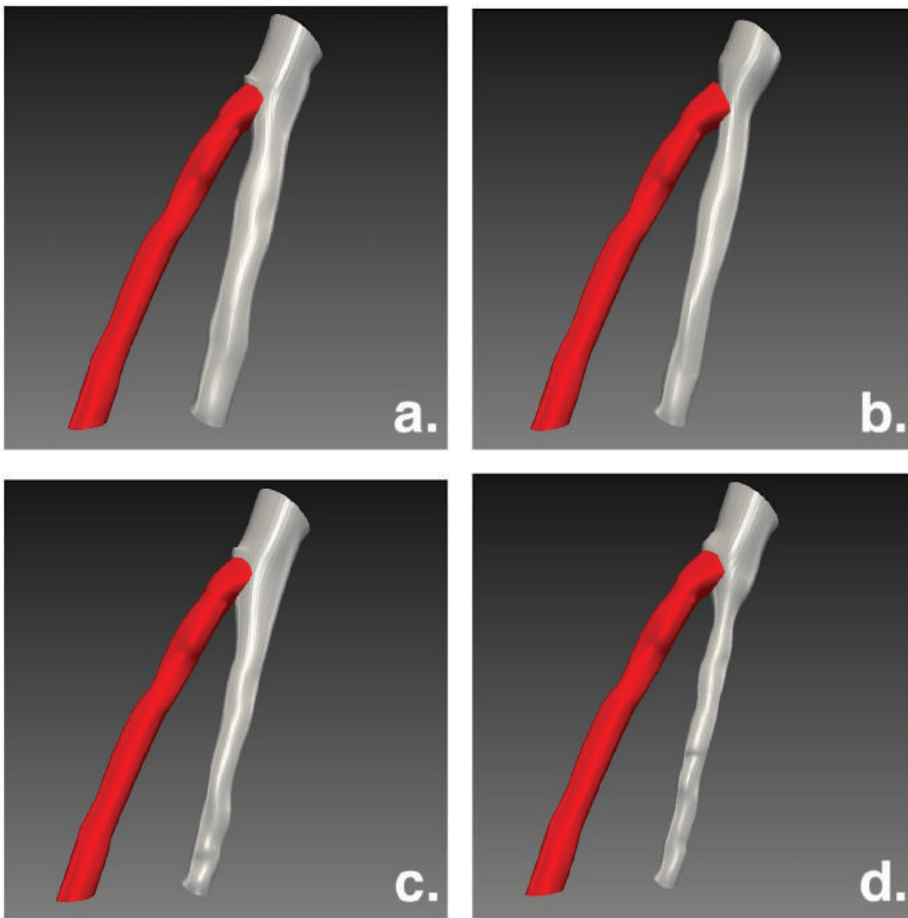


Figure 7.

Four different models with a gradual increase in percentage blockage of SFA. DFA is in red and CFA & SFA are in grey (a) DFA & Grade 0 SFA model (b) DFA & Grade 1 SFA model (c) DFA & Grade 2 SFA model (d) DFA & Grade 3 SFA model

the cumbersome numerical values of WSS, the results in this pilot prediction system are categorized into four different levels with distinct colors in a color contour map of the femoral segment, as shown in Figure 9. The four levels are named as “low,” “average,” “high,” and “very high.”

The “low” level includes values of WSS below 0.4 Pa^{12} and will be presented in a dark blue color. Regions along the arterial wall displayed in this color may be prone to atherogenesis, as previous studies have suggested that low shear stress conditions may promote the formation of atherosclerotic plaque, possibly due to enhanced mass transfer through the arterial endothelium that leads to a gradual accumulation of material in the arterial

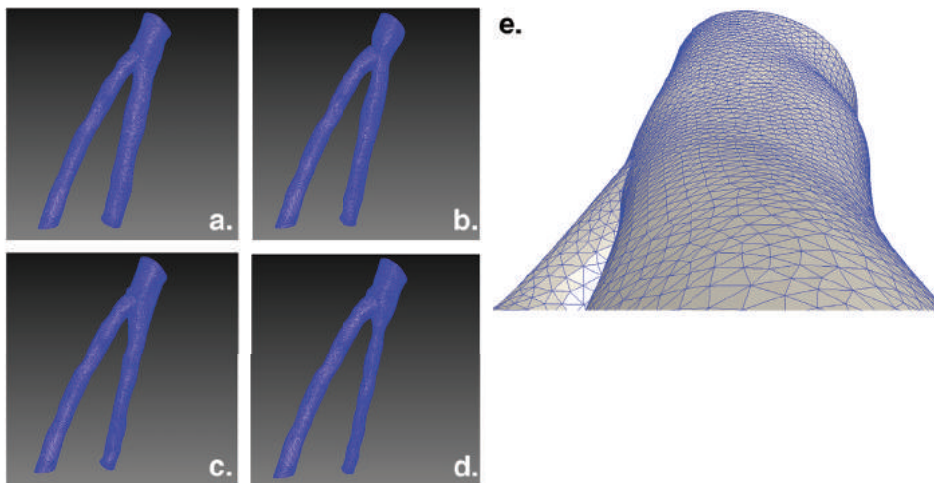


Figure 8.
Meshes of the femoral artery bifurcation (a) Grade 0 model (b) Grade 1 model (c) Grade 2 model (d) Grade 3 model (e) Detailed mesh of DFA & Grade 0 SFA. CFA and Grade 0 SFA is on the right.

wall.^{3,31-33} To patients, a large area of dark blue means that regular check-ups are encouraged in order to treat the plaque as soon as it is noticed. A healthy diet and lifestyle should also be encouraged. Risk factors that may accelerate the atherogenesis, such as smoking, diabetes and hypertension, should be prevented and treated in a timely manner.³⁴ The “average” level includes WSS with a value between 14 and 22 dynes/cm², which is the range of mean WSS in the proximal SFA.²⁸ Displayed in the color green, “Average” means that this segment of the vessel is relatively healthy. The “high” level covers values of WSS that are above average but below the rupture threshold. Represented by the color orange, this level shows the presence of atherosclerotic plaque and a possibility of plaque rupture as WSS is reaching the ultimate rupture threshold. Therapies, like smoking cessation, lipid-lowering therapy, and hypertension management should be used to lower cardiovascular risk and decrease the rate of PAD progression.³⁴ Antithrombotic medications, such as Aspirin and Thienopyridines, could be prescribed to reduce the possibility of vascular events.³⁴ The ultimate “very high” level is indicated by the color red, and shows that WSS is above 300kPa,¹⁵ a critical threshold suggested for the carotid artery, which shares a similar luminal diameter with the model in this study. According to a previous case study, the weakest region is at the upstream highest WSS region of the vulnerable plaque.¹² Another study found that 63% of fatal plaque rupture occurred at the lateral

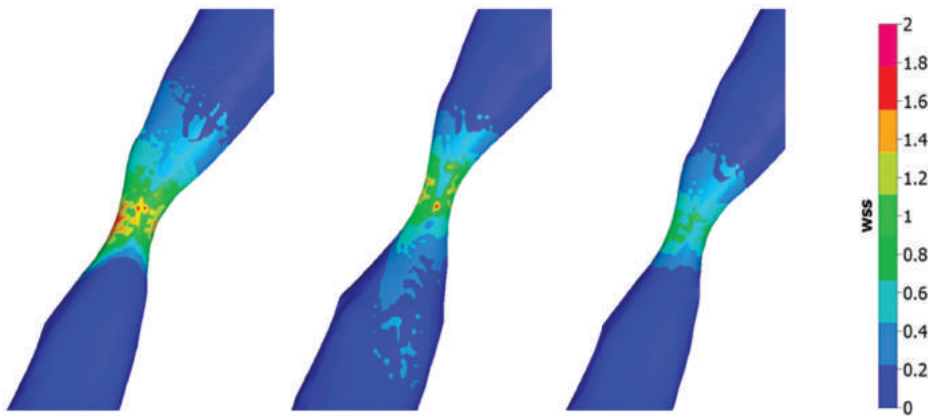


Figure 9.

An illustration of what the side views of WSS distribution obtained from the CFD simulation are going to be like. Results of WSS in 4 different models will be shown in 4 color contour maps with a labelled scale on the right. WSS in different levels will be shown in different colors along the vessel. Figure reproduced from figure 9 in <30>. The original figure is a comparison of WSS for varying aqueductal stenosis

cap shoulders, where the plaque joins the healthy intima,²⁹ possibly resulting from a long-term repetitive cyclic tensile stress that causes cap fatigue¹⁶. Therefore, regions in red are warning signs of plaque rupture at upstream or lateral cap shoulders. Endovascular treatment or surgeries are required immediately to treat the plaque; otherwise, lesions may give rise to femoral thrombosis, which may break off and clot the coronary artery.³⁹

It should be noted that there are some limitations to this study. Limited resolution of CT scan images and the artificial judgment of wall boundary make it difficult to accurately segment the real arteries. For example, determination of the radius of a stenosed arterial lumen may not be accurate due to the methods of counting pixels. Moreover, the distance between contoured slices may be great enough that the detail of the wall and curvature may be lost. Furthermore, the arterial wall was assumed to be rigid due to the complexity of numerical modeling, and this may not reveal the real flow distribution in elastic arterial walls. Smaller branches of SFA and DFA were intentionally removed in the model of this study. Thus, the modeled vascular flow may not reveal this in actuality.

4. Conclusions

In this paper, a new computational model of the progression and rupture of plaque in the femoral artery was built. A pilot system with four identified

thresholds was created to establish a link between WSS and plaque formation or rupture. With the advantageous specificity of the CFD model, personalized blood flow simulations could be carried out later with the model designed in this study to analyze complex flow distribution and vascular conditions in different patients. With future advancement in medical imaging techniques, a better resolution may contribute to a more detailed, realistic model. Models of femoral atherogenesis could also be built with compliant walls to mimic real arteries. Smaller branches of the SFA and DFA could also be added to the model. Moreover, other parameters including mechanical stress, flow rate, composition of plaque, and cap thickness could be combined with WSS in a more complex model. With the power to provide the physicians and patients with a highly specific and accurate analysis of the femoral artery and other arteries prone to atherosclerosis, CFD simulation has great potential in the future of the personalized health care industry.

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Macrophage Migration Inhibition Factor

A Cancer Promoter, Potential Prognosticator
and Chemotherapeutic Target

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Abstract

Cancer has been perplexing humans with its low survival rate, recurrence and complexity of pathogenesis. The immune system theoretically should be able to detect DNA mutations and force abnormal cells to undergo cell arrest or apoptosis. However, some inflammatory immune cells and proteins are observed to assist cancer growth (Nobre et al., 2017).

Among these immune cells, macrophages are in charge of cleaning up infections, inducing inflammation, presenting antigens to lymphocytes and initiating cell repair. However, when tumor cells convert macrophages into a tumor-supporting phenotype known as tumor-associated macrophages in a paracrine pathway, macrophages overexpress some cytokines that have pro-tumorigenic effects (Immunology).

Among the cytokines that are associated with cancer proliferation, macrophage migration inhibition factor (MIF) plays a critical role as an upstream regulator of multiple signal transduction pathways that are responsible for creating a suitable environment for cancer growth. It contributes to tumor growth by promoting delayed apoptosis, Epithelial-Mesenchymal Transition (EMT), angiogenesis and hypoxic micro-environment (Wang et al., 2017). This paper explains the mechanisms of how MIF becomes a pro-tumorigenic factor, elaborates on

the nuances of MIF's impact on different types of cancer and analyzes the potential antagonists to counteract MIF's effects with an emphasis on small-molecular weight substances. Then, hypothetical experiments are proposed to establish MIF as a prognosticator and a potential therapeutic target by investigating the effectiveness of anti-MIF substances.

1. Basics of Macrophage Migration Inhibition Factor

1.1 What is MIF

MIF gained its name from its inhibitory role in random migration of macrophages (Nobre et al., 2017). It was originally discovered as a lymphokine that mediates delayed hypersensitivity and various macrophage functions, including phagocytosis and tumoricidal activity (Nishihira, 2004). It is primarily a pro-inflammatory protein produced by almost all types of somatic cells, and an immunomodulator in T-cell activation and antibody production. Tumor cells produce MIF as an autocrine signal to upregulate inflammatory cytokines that promote cancer growth and downregulate the expression of tumor suppression genes. High levels of MIF are found in almost all types of cancer in all stages of development (Nobre et al., 2017).

1.2 How MIF Promotes Cancer Development

MIF is an autocrine regulator of cell proliferation. When MIF expression cannot be modulated, it can cause chronic inflammation and epithelial cell injury that leads to carcinogenesis (Meyer-Siegler et al., 2006).

MIF regulates several signal transduction pathways that affect apoptosis, autophagy, inflammatory micro-environment, hypoxia, angiogenesis, EMT and immune surveillance (Wang et al., 2017).

Apoptosis is an important defense mechanism against tumor development because once replication errors are detected in the genome of cancer cells, the immune system drives the abnormal cells to undergo apoptosis. CD74, a transmembrane receptor on the surfaces of monocytes for MIF, triggers the ERK1/2 MAPK cascade, resulting in increased cell proliferation via cyclin D1 transcription. Cyclin D1 helps tumor cells pass the checkpoint between the G1 and S phase by suppressing the CKI family that blocks the transition and upregulating positive regulators like CDK. ERK1/2 kinase phosphorylation then mediates CD44, a transmembrane coreceptor. Long-term enhanced activation of CD44 is responsible for promoting cancer invasion because it helps the formation of pseudopods to enable cancer cells

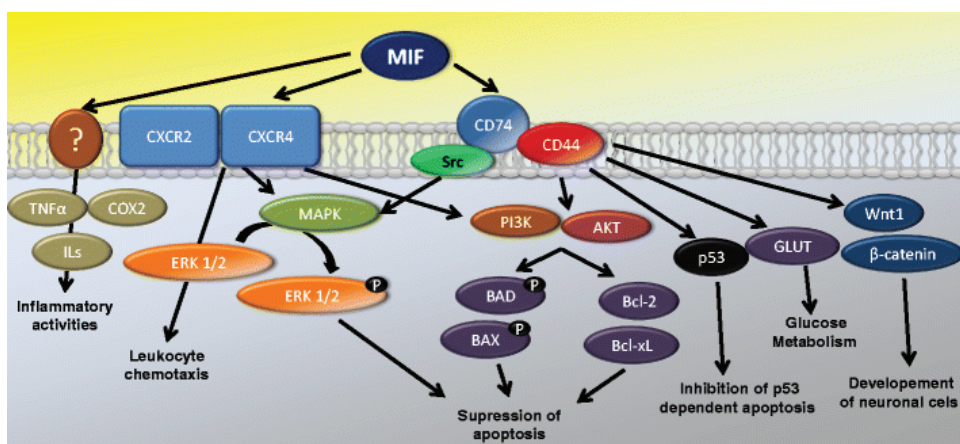


Figure 1.

The signaling pathways and metabolic activities that are regulated by MIF. The arrows point from the regulator to the compound being regulated. (Photo credit: Springer, Pathology & Oncology Research, Nobre et al., 2016)

to migrate, and the infiltration of lymph cells back to lymph nodes to lay groundwork for cancer metastasis (UniProt).

MIF is an antagonist of p53-dependent apoptosis, a direct barrier against tumorigenesis. In normal cells, p53 is bound to its inhibitor. Once replication error is detected, the inhibitor releases p53 to stop the cell cycle and repair the error. MIF stabilizes the bond between p53 and its inhibitor, preventing p53 from functioning (Nobre et al., 2017).

MIF also promotes the growth of tumor spheres and metastasis via nuclear factor—kappa B (NF- κ B) because this factor turns on the production of proteins that stop apoptosis and promotes cell proliferation. MIF also protects bone marrow-derived mesenchymal stem cells from programmed death through AMPK/mTOR signaling pathway (Wang et al., 2017).

Autophagy is the maintenance of the homeostasis of cells through regulated mitosis, differentiation and death. Autophagosomes are formed to break down organelles and recycle organic materials, while preventing the accumulation of genetic mutations or toxic chemicals in the cytoplasm. Inhibiting autophagy is thought to be beneficial to cancer. Defective autophagy leads to tumorigenesis in the liver, lungs, and lymph nodes. MIF suppresses autophagy of viable cancer cells and promotes autophagy of endothelial cells so that cancer cells can enter the bloodstream and invade other organs (Wang et al., 2017).

MIF is a pro-inflammatory factor, and thus contributes to an inflammation micro-environment that supports cancer growth. In response to tumor necrosis factor- α (TNF- α) and interferon, macrophage-released MIF increases, causing the increase of the production of Nitrogen Oxide

and TNF- α in an autocrine fashion. At the same time, MIF inhibits the mitochondria-dependent death pathway to reduce the rate of apoptosis in neutrophil granulocytes so that bacterial infections can be cleaned out. CCL4 and MMP9 are secreted by neutrophils and the two ligands are involved in tumor progression. MIF also contributes to lymph node metastasis by upregulating Interleukin-8 (IL-8) expression. IL-8 guides neutrophils and lymphocytes to migrate to a chemical stimulus, but can also be a mitogenic, motogenic and angiogenic factor for cancer (Wang et al., 2017).

When blood supply cannot meet the needs of rapidly growing tumor cells, hypoxia (lack of oxygen) results. Tumor cells secrete hypoxia-inducible factor-1(HIF) that induces MIF secretion and causes delayed senescence, anaerobic tumor growth, resistance to therapy, and metastatic adaptation. MIF stabilizes HIF-1 by protecting it from degradation under an aerobic environment. If MIF, a crucial effector of HIF, is eliminated, therapies can be enhanced and it will be hard for the tumor to metastasize. The effect of HIF on MIF level can be done without direct regulation. There are other specific hypoxia-induced regulatory mechanisms for the up-regulation of MIF in breast cancer. (Brahimi-Horn et al., 2007; Wang et al., 2017).

Besides utilizing hypoxia, tumor cells also induce angiogenesis to sustain their unrestrained growth. The newly formed vasculature is chaotic and leaky so that tumor cells can enter the blood stream easily and metastasize via the vascular system. Vascular endothelial growth factor (VEGF) is upregulated by MIF. IL-8, as mentioned above, also contributes to angiogenesis (Wang et al., 2017).

EMT is the conversion from a polarized epithelial cell phenotype into a mobile mesenchymal cell phenotype through suppressing the expression of adherent protein E-cadherin and over expressing mesenchymal markers, such as N-cadherin and vimentin. This process is critical for epithelial-derived cancer cells to metastasize. There are transcription factors that regulate this process by controlling the expression of proteins involved in cell polarity, cell-cell adhesion, cytoskeleton structure and extracellular matrix degradation, initial invasion and metastatic dissemination of carcinoma cells. MIF plays a role in this process by upregulating the expression of transcriptional factors of the EMT such as Twist and Snail. The exact mechanism of how MIF regulates EMT is still unclear, but it will be the key to understanding the relationship between MIF and EMT and developing anti-MIF medicine to blockade EMT (Wang et al., 2017).

MIF protects tumor cells from anti-tumor immunity. It suppresses the production of dendritic cells, natural killer cells and cytotoxic T lymphocytes and inhibits the functioning of existing ones. Moreover, MIF activates myeloid-derived suppressor cells (MDSCs) and tumor-associated macrophages (TAMs)

to serve as immune suppressors. MIF reduces the number of M1 macrophages and thus decreases their ability to form organized aggregates in the spleen by inhibiting the migratory activity. As a result, M1 macrophages cannot engulf tumor cells, while M2 macrophages, which organize cell repair, are recruited to boost cancer growth (Nobre et al., 2017).

2. Association between MIF and Different Types of Cancer

MIF has been found to correlate with the advancement of different types of cancer. MIF antagonists have been proved to suppress cancer development in a dose-dependent manner. In addition to MIF's roles in promoting the common features of cancer discussed in the previous section, there are also nuances in how different types of cancer utilize MIF.

2.1 Prostate Cancer

Serum MIF levels are significantly higher in prostate cancer patients; MIF levels correlate with clinical scores and Gleason scores (a scoring system clinically used to stage prostate cancer) ($p < 0.05$)—patients with higher MIF levels often have worse prognoses (Tang et al., 2011).

There are two prostate cancer cell lines—androgen-dependent (LNCaP) and androgen-independent (DU-145). MIF receptor CD74 was only detected in the latter. ISO-1, an MIF inhibitor, only reduces MIF tautomerase activity and cell proliferation in DU-145 cells but has little effect on LNCaP cells and normal prostate cancer cells. This indicates that MIF is only influential in androgen-independent prostate cancer, while androgen-dependent prostate cancer does not necessarily rely on MIF to proliferate. Anti-MIF treatment and the use of MIF as a prognosticator might only work for DU-145 cell line prostate cancer (Meyer-Siegler et al., 2006).

Sexually transmitted infections also increase the risk of acquiring prostate cancer because infections trigger an increase in the production of pro-inflammatory factor MIF. In addition, a human-infective parasite *Trichomonas vaginalis* also produces its own MIF that is 47% similar to human MIF and binds to CD74 with high affinity, causing similar carcinogenic effects as human MIF. Therefore, chronic *T. vaginalis* infections can contribute to the development of prostate cancer (Twu et al., 2014).

2.2 Lung Cancer

Lung cancer is one of the most common and lethal types of cancer worldwide. The 5-year survival rate is as low as 16%. MIF levels correlate with

the level of angiogenesis in non-small cell lung cancer. When lung cells are damaged by smoking, occupational exposure to industrial exhaust, electromagnetic radiation, chronic infections or air pollution, MIF is produced to foster inflammation and cell repair. Since the damaged cells are likely mutated, MIF also acts as an enzyme that catalyzes the tautomerization critical to cancer development with an unknown mechanism. Initial studies have shown that SCD-19, an inhibitor of tautomerization, at 100 $\mu\text{mol/L}$ was effective in attenuating lung cancer growth both *in vitro* and *in vivo*.

The Warburg effect is the distinctive glucose metabolism of cancer cells that might help promote uncontrolled proliferation. Even in the presence of oxygen, cancer cells tend to produce ATP in an inefficient way by only carrying out glycolysis. Nutrient supplies from the extracellular environment are always abundant for cancer cells because of angiogenesis. Cancer cells have enough glucose to be processed inefficiently. But cancer cells do need to replicate cellular components quite rapidly in their shorter interphase. This special metabolic process enables cancer cells to meet metabolic requirements other than ATP production by using glucose to generate vital compounds for molecular synthesis to create the cellular components (Heiden et al., 2009). MIF promotes the Warburg effect in lung cancer cells by upregulating hypoxia-inducible factor 1- α (HIF-1 α), which in turns contributes to the proliferation of lung cancer cells (Li et al., 2018).

As one ages, one's ventilatory capacity reduces, exposure to carcinogens accumulates and vulnerability to environmental stressors increases. Even when the immune system is compromised by age, it still helps repair alveoli damage and promotes inflammatory pathogenesis of cancer at the same time. Immunohistochemistry tests (IHC) demonstrate the overexpression of MIF and CD74 receptor in patients with non-small cell lung cancer (Sauler et al., 2015).

2.3 Head and neck squamous cell carcinoma (HNSCC)

The serum MIF level of HNSCC patients reached approximately three times that of their healthy counterparts (Wang et al., 2017). HNSCC can be caused by tobacco use and human papillomavirus (HPV) infections. As substances in tobacco and HPV inflict harm on normal squamous cells, cells express high levels of MIF to promote the repair in the outer layer of skin and mucous membranes, contributing to the development of cancer (NIH). Ultraviolet B-rays can cause genetic mutations by linking consecutive pyrimidine dimers covalently. Long-term exposure upregulates MIF expression. But inhibitors of MIF protect the squamous cells against tumorigenesis even after acute and chronic UVB exposure.

2.4 Gastric Cancer

Gastric cancer can result from bad eating habits—consuming a lot of smoked and pickled food as well as not having meals regularly, infection of *H. pylori* bacteria and long-term pressure. It has similar symptoms to stomach ulcers and gastritis, so patients often ignore the discomfort and are not diagnosed with gastric cancer until the advanced stages (Cancer.gov).

MIF expression in gastric cancer tissues was found to exceed that in adjacent normal tissues ($P < 0.001$). High levels of MIF correlated with advanced tumor stage, more severe lymph node metastasis, and poor patient survival rate ($P < 0.05$ for all) (He et al., 2015).

MicroRNA-1228* (miR-1228*), which arrests gastric cancer cells at G0/G1 phase to prevent them from proliferation, is downregulated in gastric cancer. MIF is a direct target of miR-1228*. The expression of MIF increases in the absence of miR-1228* (Jia et al., 2017). *H. pylori* infection increases MIF polymorphism and expression. It could be a result of cells responding to the endotoxin and releasing MIF to induce inflammation. Similar to the adaptations of intestine macrophages to *E. coli*, long-term exposure may even change the gene expression of macrophages in the stomach to acclimate to the existence of *H. pylori*, contributing to polymorphism. Consequently, one will be more susceptible to gastric cancer as MIF takes more forms and increases its expression (Li et al., 2012).

2.5 Pancreatic Cancer

Orphan nuclear receptor NR3C2 is a tumor suppressor. It inhibits EMT and enhances the sensibility of prostate cancer to gemcitabine, a chemotherapeutic drug used in pancreatic ductal adenocarcinoma patients. MIF increases the production of microRNA-301b that suppresses the expression of NR3C2. This results in the poorer survival of pancreatic cancer patients (Yang et al., 2016).

2.6 Ovarian Cancer

In ovarian cancer, MIF is overexpressed in both solid tumors and ascites-derived tumors. It correlates to the malignancy of ovarian cancer. Natural killer cells need to recognize stress-induced cells before they kill ovarian cancer cells. MIF, however, downregulates one of the important signal ligands, NK group 2D, that indicates DNA damage. Consequently, ovarian cancer cells can escape from immunosurveillance (Krockenberger et al., 2008).

2.7 Exceptions

Not every kind of cancer is associated with the overexpression of MIF. HPV positive oral cavity carcinoma is related to lower concentrations of MIF (Wang et al., 2017). Unlike others, this type of cancer might be detected from a low concentration of MIF and could not be treated with anti-MIF substances. In addition, intracellular expression of MIF was proved to be beneficial in eliminating breast cancer, whereas extracellular expression of MIF is pro-tumorigenic (Verjans et al., 2009).

3. Significance of MIF

MIF seems to cause considerable trouble for humans, and there are many other inflammatory factors that have similar functions to MIF. However, MIF's function in the human body is far more complicated. MIF knockout causes disturbance to insulin sensitivity in the hippocampus, leading to memory difficulties and anxiety (Djordjevic et al., 2017). The deficiency of MIF also impairs tubular cell regeneration (Ochi et al., 2017). MIF losses aggravate age-inducing cardiac remodeling and dysfunction (Xu et al., 2016). MIF protects cochlear cells from oxygen-glucose deprivation injury, thus preserving hearing function (Zhu et al., 2018). Sufficient MIF is important to allow more time for stroke patients to be free from permanent brain damage. The downregulation of MIF under hypoxic conditions (associated with cancer micro-environment) accelerates neuronal death (Zhang et al., 2014). MIF plays a preventive role in amyotrophic lateral sclerosis (ALS) (Shvil et al., 2018). MIF is critical to maintaining the normal functions of several types of cells and organs. Since knockout of MIF gene can cause the problems mentioned earlier in this paragraph, scientists can target antagonists of MIF to decelerate cancer development and even reverse the process.

4. How MIF Can Be Controlled: Comparing and Contrasting the Advantages and Disadvantages of Different Treatments

4.1 Using Small-molecular Weight Inhibitors to Block the Activity of Existing MIF

4.1.1 *Glucocorticoids (GC)*

MIF can be counteracted by GC, especially in lymphatic cancer (Wang et al., 2017). GC are a group of anti-inflammatory hormones that can be made by human bodies. It regulates sugar and fat metabolism in cells. It can not

only suppress harmful immune responses in allergies, autoimmune diseases and asthma, but also maintain sufficient inflammatory proteins by manipulating the protein expression in lymphocytes. It has been widely used in treating inflammatory bowel diseases, rheumatoid arthritis and transplant rejection (WedMD).

4.1.1.1 COMBINED THERAPY

GC does not work well by itself when used to target MIF in cancer. Anti-folate (downregulate amino acid and purine biosynthetic pathways), cyclophosphamide (inspired by mustard gas in WWI that can deplete bone marrow and lymph nodes), vincristine and asparaginase (cancer cells cannot synthesize asparagine, this enzyme can starve the cells), can work in conjunction with GD. So far the remission has proved to be temporary. More work needs to be done to prolong the effect of this therapy; it also has to be administered in early stages (Pufall, 2017).

4.1.1.2 SIDE EFFECTS

Long-term intake of GC at high doses can lead to mild side effects like weight gain, fat redistribution bone fracture for those with low bone density and older ages, osteoporosis that can be treated with teriparatide. Other severe adverse effects include osteonecrosis (death of bone tissue) that becomes rare when doses are below 20 milligrams per day, cataracts, diabetes, heart failure, infections, ulcers, etc. (Gensler, 2013). Future studies should pay attention to ways of modifying BIM and BCL2, regulators of apoptosis in bones to prevent osteonecrosis, and how to deliver GC specifically to the cancer tissue without affecting the healthy tissues. The effectiveness of GC might be enhanced by administering GC cofactors, which vary in different tissues. In this way, GC administered at low doses will still be effective and huge side effects can be avoided. Currently, there are multiple kinds of GC to use for different diseases. The questions of which one to use for different types of cancer, at what dose, and for how long are still concerning physicians. The underlying mechanisms of how GC regulates lymphocyte distribution need to be figured out before the actual application.

4.1.1.3 RESISTANCE

Acute Lymphoblastic Leukemia patients exhibit resistance to GC treatment, higher expression levels of the anti-apoptotic genes counteract GC; for adults, survival rate is much worse because adults cannot tolerate the treatment as well as children. The chemicals have to be given in pulses instead of continuously, so a bone marrow transplant is preferred over GC treatment.

4.1.1.4 ANTI-EMETIC AGENTS

Besides their potential in treating cancer, GC can be used as an anti-emetic agent to relieve side effects of chemotherapy, such as vomiting, hypersensitivity and skin rashes (Wang et al., 2017).

4.1.2 *Fucosidase or Sialidase*

The glycolipid receptor of MIF contains fucose and sialic acid (David et al., 1983). By administering fucosidases (to cut off fucose) or neuraminidases (to cut off sialic acid), targeted cells of MIF are no longer able to respond to MIF due to the disintegration of the MIF receptor.

Fucosidases are enzymes found in lysosomes that are used to digest recycled organic materials (NIH). Studies have shown the beneficial role of fucosidase in inhibiting cancer growth. α -L-fucosidase-1 (FUCA-1) is highly expressed in a normal thyroid but down regulated in thyroid carcinoma. It inhibits the activation of epidermal growth factors. It can make cancer cells less invasive and even lead to cell death, although the exact mechanism remains unknown. But thyroid cancer cells could not adhere to normal endothelial cells when treated with bovine FUCA-1, thus slowing down the process of metastasis (Vecchio et al., 2017). The reduced expression of FUCA-1 is associated with recurrence and shorter survival in luminal B LN+ breast cancer patients (Bonin et al., 2018). However, FUCA-1 is overexpressed in the serum of oral cancer (Vajaria et al., 2013). FUCA-1 might only be useful in treating certain types of cancer like thyroid cancer and luminal B LN+ breast cancer, but not oral cancer.

Sialidases, also called neuraminidases, can catalyze the cleavage of sialic acid from glycolipids. Abnormal sialylation is a feature of cancer cells with invasiveness and metastatic properties, but it can be regulated by sialidase to diminish the threats from cancer cells (Vajaria et al., 2016). Not all sialidase can be used in treating cancer. A subtype of sialidase, plasma membrane-associated ganglioside sialidase (NEU3), is upregulated in prostate and colon cancer (Hata et al., 2015). Lysosome-associated sialidase (NEU1) is highly expressed in ovarian cancer patients (Ren et al., 2016). Therefore, only cytosol-associated sialidase (NEU2) and NEU4 sialidase might be safe for treating cancer (Miyagi & Yamaguchi, 2012).

The problem with fucosidase or sialidase is how to make sure the enzymes only disrupt MIF receptors. If the enzymes accidentally disintegrate other receptors that also contain fucose or sialic acid, corresponding metabolic activities could be harmed and cause serious adverse effects.

4.1.3 Cell Surface Proteinases

The response to MIF is limited by cell surface proteinases, which degrade the mediators of cellular response to MIF. Diisopropylphosphorofluoridate or plasma proteinase inhibitors can block these cell surface proteinases to enhance the effects of MIF (David et al., 1983).

Studies of how cell surface proteinases interrupt the MIF signaling pathway are limited. Further studies are needed to develop cell surface proteinases as potential chemotherapy medication.

Exposure to diisopropylphosphorofluoridate or plasma proteinase inhibitors should be limited. Diisopropylphosphorofluoridate is used to treat glaucoma, while plasma proteinase inhibitors are used to treat human immunodeficiency virus (HIV) infection. Cancer patients who are also diagnosed with these two diseases might need to be treated with other MIF antagonists.

4.1.4 Trypsin

A fibronectin-like surface material is required on the macrophage for the cell to manifest migration inhibition. This material can be removed by trypsin and this removal is reversible by incubating macrophages in a fibronectin-like substance (David et al., 1983). Once cancer is no longer detectable, patients can take in fibronectin-like substances to restore the MIF signaling mechanism to help with inflammation.

Trypsin has been used to treat ulcers (by removing dead tissues and promoting cell repair), maldigestion (by acting as a digestive enzyme) and osteoarthritis (WedMD). It could possibly be used in cancer treatment but needs further research. Since this substance is profoundly studied and applied, it would be easy to use the drug because the manufacture of trypsin is already mature.

However, trypsin has also been found to contribute to colorectal carcinogenesis. Therefore, it might be able to treat other types of cancer, but not colorectal cancer (Soreide et al., 2006).

The side effects of trypsin are less severe than other inhibitors. It causes fever or chill, dizziness and rapid heart rate (Drugs.com).

4.1.5 Eliminating Endotoxin that Can Enhance MIF Action on Macrophages

Endotoxins are a component of the outer membrane of the cell wall of bacteria. They are protective barriers against lysozyme secreted by the animal host. They also ensure that only certain hydrophilic molecules with low molecular weight can enter the cytoplasm to maintain chemical homeostasis. They induce inflammatory responses in the human body, so MIF production might be enhanced to deal with the bacterial infections (David et al., 1983).

Endotoxin is made of three parts: lipid A for cell viability, O antigen for host-parasite interactions and core antigen for permeability properties; all contribute to the virulence. Future studies could focus on how to target the three parts separately to reduce endotoxin (Todar).

To eliminate the exposure to endotoxins, cancer patients should avoid bacterial infections by wearing breathing masks, sterilizing living space regularly and minimizing exposure to crowded places. Some oxidizing agents like superoxide, peroxide and hypochlorite might be able to neutralize endotoxin. These disinfectants, when at high concentration, can cause skin irritation, eye damage and inhalation problems; but they can all be broken down by enzymes/organelles that naturally exist in human bodies—superoxide dismutase and peroxisome. When MIF is contained, the body will catabolize the excess of the disinfectants itself. This method of applying disinfectants is significantly easier to do and cheaper than other anti-MIF substances.

Interestingly, there are studies that found an inverse association between exposure to endotoxins and the risk of lung cancer. Since the studies were conducted on people with occupational exposure to endotoxins, the conclusion may not apply to those who are not exposed to endotoxins at work (Khedher et al., 2017). A detoxified endotoxin derivative, Monophosphoryl Lipid A (MPL[®]) was even invented as a human vaccine against cancer (Mastrangelo et al., 2013). There are also studies that show no association between endotoxins and pancreatic cancer (Reul et al., 2016). Since the exact mechanism of how endotoxins affect cancer development is unclear, it is prudent not to reduce endotoxins or use endotoxins to treat cancer. This method is controversial compared to others.

4.1.6 Eliminate Phorbol Myristate Acetate (PMA)

PMA is a type of phorbol ester abundant in croton oil. It is also known as tetradecanoylphorbol acetate. It is active even at nanomolar concentrations. It has potential antineoplastic effects because it controls multiple gene expression and can lead to apoptosis. But it also promotes cancer, especially leukemia, because it induces the maturation of leukemic cells (PubChem). It is needed for macrophages to express the MIF receptor and, therefore, plays a role in inhibiting p53 (David et al., 1983). It can increase some tumor suppressor genes like p21 but suppress others like p53 through the MEK/ERK-dependent pathway. Different cells respond differently to PMA. Compared to other treatments, PMA is controversial in its administration because it can be both beneficial and harmful for cancer growth. Interestingly, PMA can increase p21 without suppressing p53 in breast cancer cells. Once this mechanism is fully studied, PMA could be promising for applications to other types of cancer (Han et al., 2011).

Esterase can hydrolyze PMA into two products that do not exhibit tumor-promoting activities. Esterase has a half-life of about 24 hours. This property is a double-edged sword because on one hand, it can be degraded quickly to minimize any potential side effects, but on the other hand, it might only cause a rapid, weak change in MIF levels and frequent administration of the substance can be inconvenient (Chandrika et al., 2017). It is wise to control the intake of croton oil and hold back PMA/esterase treatment until the pathways to maximize both p21 and p53 expression are understood.

4.1.7 Isothiocyanates (ITC)

ITC, hydrolysis products of glucosinolates normally obtained from cruciferous vegetables, can inhibit MIF. ITC covalently modify MIF with a local conformation at Pro-1 and by doing so, inhibit MIF-mediated pro-tumorigenic activities (Crichlow et al., 2012). Additionally, as biotransformation enzymes, ITC clean out carcinogens and induce apoptosis by inactivating proliferation markers (Oregon State University).

Not enough is known about proper dosage and timing of administration for therapeutic uses. Some found that only administration prior to or during tumorigenesis is effective. Others reported only high isothiocyanate dosage induces apoptosis (Crichlow et al., 2012).

The findings on ITC provide a nutritional therapy against cancer. Patients can simply include more cabbage, broccoli, cauliflower, watercress, kale, etc. in their meals. The vegetables have to be lightly cooked to minimize the inactivation of myrosinase, the enzyme for glucosinolate hydrolysis. ITC conversion can then be optimized. ITC have not been found to have any adverse effects or negative interactions with other drugs, making them an ideal nutritional supplement against cancer.

4.1.8 (S,R)-3-(4-hydroxyphenyl)-4,5-dihydro-5-isoxazole acetic acid methyl ester (ISO-1)

The exploration of this MIF antagonist is still in the preliminary stage. It was found to be significantly effective in alleviating the degree of inflammation by inactivating factors like TNF- α , interleukin-1 β , and interleukin-6 controlled by MIF. ISO-1 can attenuate MIF-caused inflammation that is insensitive to glucocorticoids. If the patient is not responding to glucocorticoid treatment, ISO-1 might be helpful (Russell et al., 2016).

4.1.9 4-iodo-6-phenylpyrimidine(4-IPP)

The insertion of a single amino acid besides Met-2 at the hydrophobic site of MIF by 4-IPP leads to complete disruption of its enzymatic and biological functions. 4-IPP has relatively low half maximal inhibitory concentration

(IC₅₀)—5 μ M—compared to other prototypical MIF inhibitors like ISO-1 (50 μ M), which means MIF is more sensitive to 4-IPP than to ISO-1 at the same concentration. 4-IPP is a suicide substrate to MIF because it binds to MIF covalently and irreversibly. Therefore, 4-IPP inhibits MIF-dependent cell migration and anchorage-independent growth in human cancer cell (Winner et al., 2008). 4-IPP treatment should be comparably more effective but cheaper (similar sales price) and less likely to cause serious side effects because of lower dosage.

4.1.10 CPSI-1306

CPSI-1306, a MIF antagonist, could enhance keratinocyte apoptosis and inhibit the UVB-induced epidermal proliferation by promoting p53 expression, which antagonized UVB-induced squamous carcinogenesis (Nagaranjan et al., 2014).

4.2 Neutralizing Antibody

Neutralizing antibody to MIF was able to reduce the survival of MIF-expressing CLL cells *in vitro* to levels comparable with MIF-deficient CLL cells.

4.3 Receptor Inhibitors

This method is not practical because MIF receptors also bind to other ligands that carry out important biological functions. In addition, cells without receptors can still respond to MIF (Hussain et al., 2013).

5. Method and Data to Be Collected: Investigating Clinical Significance of Macrophages in Cancer Prognosis and Treatment

5.1 MIF as a Biomarker to Detect and Stage Prostate Cancer

MIF has high prognosis values. Macrophages help infiltrate tumors, making prognosis difficult, but MIF levels are more detectable and are a direct indicator of tumor. They can even be used to predict the stages of cancer progression.

Method: Randomly collect a large sample (at least 30) of serum MIF level from healthy people (without cancer, rheumatoid arthritis, injuries/infections, autoimmune diseases and other diseases that have been found to be associated with MIF (Wang et al., 2017)). Randomly collect a large sample of

serum MIF levels from cancer patients without the diseases mentioned above and with only one type of cancer. These cancer patients should be undoubtedly diagnosed with cancer by using multiple diagnosis methods such as imaging, biopsy, etc. The sizes of the control group and the cancer patient group will preferably be the same. Serum samples of the cancer patients should be collected from fingertip, primary site of cancer, and secondary site if there is one, because MIF levels are most differentiable near the sites where MIF is needed for cell proliferation. Categorize the sample of cancer patient first by the types of cancer, then by stages of cancer progression (use common staging method TNM staging system or other systems if there is a better one for a specific type of cancer, e.g. Gleason scoring for prostate cancer). At least 30 patients are needed for each stage of cancer. Test MIF expression by reverse transcription-polymerase chain reaction (RT-PCR) and Western blot. MIF mRNA was analyzed by RT-PCR, and MIF and proliferating cell nuclear antigen (PCNA) proteins were detected by Western blot (He et al., 2015). If the funding permits it, enzyme-linked immunosorbent assay (ELISA) is preferred over Western blot because of its accuracy, sensitivity and specificity (Sino Biological). Monoclonal antibodies specific to MIF can also be used with the help of IHC.

Perform the following statistical tests if the distribution of MIF expression is a Gaussian distribution:

1. Unpaired 2-sample t test—to compare the mean MIF levels between the control group and different types of cancer patients (ignore different stages for now). If $p < 0.05$, then there is significant evidence to infer that cancer patients have different MIF levels from healthy individuals; thus MIF can be an effective prognosticator of cancer.
2. One-sample t interval—95% confidence interval of mean MIF of patients with one type of cancer to determine the MIF level that indicates the presence of this specific type of cancer. Repeat the procedure with other types of cancer. This value can be useful for healthcare providers to diagnose cancer in addition to current methods like biopsy, imaging equipment and lab tests. MIF should be also included in annual physical examination for susceptible individuals because even though common tests cannot tell the presence of a tumor, MIF is an indicator for abnormality.
3. Chi-square test for association—to determine if there is an association between the stage of cancer and MIF level. If $p < 0.05$, then there is significant evidence to infer that MIF can also help stage cancer progression.
4. One-sample t interval—if there is an association between the stage of cancer and MIF level, find the 95% confidence interval of the mean

MIF of patients with a specific type of cancer at a specific stage, and repeat with the rest of the stages and other types of cancer. This quantitative variable is a reliable and straightforward indicator of cancer advancement.

If the levels of MIF of the patients do not fall under a normal distribution, nonparametric tests like ANOVA should be used instead.

The statistical analysis can be done using software programs like Prism, Minitab or Fathom.

5.2 Use anti-MIF substances to counteract the contributions of MIF to cancer proliferation

5.2.1 Effectiveness Validation

First of all, a commercial database can be used to look for compounds that can potentially interact with the active site of MIF. The results usually are in the order of binding capability. Nevertheless, substances mentioned above should be studied thoroughly because there is already plentiful evidence for their inhibitory effects on MIF and even cancer progress.

The compounds are then tested for their inhibitory abilities against MIF. The inhibitors should be able to disturb the signaling pathway of MIF in one way or another. They can be competitive inhibitors that compete with MIF for the receptors, or allosteric regulators that alter the configuration of the receptor and MIF, or suppressors of an important component in the cellular response mechanism to MIF.

It is also important to find out how the substance is absorbed and metabolized so that cells react to it and the body can get rid of it after the treatment. Its potential benefits and mechanisms of action such as which cell lines and proteins it regulates should be understood before the next stage, especially for those that have dual roles in cancer development. IC50 should be measured to find the most effective MIF inhibitors for *in vitro* testing.

5.2.2 In vitro Testing

Different types of cancer cells are purchased. They should be maintained in a sterile environment at 37°C degrees Celsius, humidified and concentrated CO₂ (5%). Cells are cultured in RPMI 1640 with Glutamax supplemented with 10% FBS (standard growth medium) (Meyer-Siegler et al., 2006).

For the control group, only recombinant MIF is added to the medium. For the treatment group, recombinant MIF is added along with each type of inhibitor mentioned earlier. After 48 hours, cells are harvested by trypsinization and counted by a hemocytometer. Lipopolysaccharides are added

to stimulate the production of inflammatory mediators regulated by MIF. There are a few measurements to be taken to evaluate the effectiveness of the inhibitor. The amount of MIF can be test by ELISA (Mawhinney et al., 2014). Cell proliferation can be determined by colorimetric MTT assay. Cell cycle can be measured by staining the cells with propidium iodide and flow cytometry. Matrigel invasion assay can be used to assess the level of invasion and metastasis. ERK 1/2 activation can be examined by Western blotting with Abs specific to phosphorylated (activated) ERK $\frac{1}{2}$. The level of cell apoptosis can be determined by caspase-3 activity and DNA laddering. Statistical analysis (one-way ANOVA) is carried out to decide if the inhibitors make a difference in anti-tumor activities compared to the control group.

5.2.3 *In vivo Testing on Animal Models*

All animal uses should adhere to the regulations of Institutional Animal Care and Use Committee (IACUC) and be approved by IACUC.

In vivo testing should focus on how the inhibitor interacts with other drugs and treatments—some interactions might be helpful so that combined therapy can be developed, but others can be counteractive or fatal.

Animal models of different cancer types need to be used to test the effects of the anti-MIF drugs before human trials. Measurements including MIF level by ELISA, tumor size by digital caliper with the help of imaging devices available to the experimenters, oxygen level by pulse oximeter, and all the variables mentioned in *in vitro* testing should be taken before and after the treatment. Post-treatment measurements should be taken regularly to monitor the effects. After the data are collected, paired t test is carried out for each type of cancer model.

Experimenters can start with the LD50 and decrease the dosage little by little to find out the best dosage and best frequency of injection that optimizes effects without causing significant side effects.

Since anti-MIF drugs are already being studied, only those substances that show potential advantages in terms of effectiveness, cost, and side effects are worth further testing (Williams).

5.2.4 *Human Clinical Testing after Getting Approval from the FDA*

The focus of clinical trials should be the best dosage, the best way to deliver the drug (such as by mouth or injection), the best time to deliver the drug (some have to be administered before cancer development to be effective, just like vaccines), potential side effects or adverse events that can often be referred to as toxicity, and how the effects vary among different groups of people (gender, race, age, health conditions, family medical history, etc.).

5.2.5 FDA Approval and Safety Monitoring

After being approved by the FDA for entering the market, the developers of the drug should continue to monitor its effects including if the expected benefits are seen and if unexpected adverse events were experienced by patients. If multiple therapeutic failure or serious adverse events are found, the developers should halt the sales of the drug, report to the FDA and make the necessary adjustments before the drug is available on the market again.

6. Discussion

MIF, a pro-inflammatory protein, is an upstream regulator of multiple signaling pathways that influence cancer proliferation by inducing angiogenesis, EMT and hypoxia as well as suppressing cell death and immune surveillance. The exact process of how MIF is involved in tumorigenesis varies among different kinds of cancer, but almost all types of cancer are related to the overexpression of MIF, making it a potential candidate for cancer prognosis and treatment. There are a few substances that should be specifically examined because of pre-existent evidence of their inhibitory quality against MIF and cancer. These substances interfere with MIF binding by degrading its receptor, modifying MIF and reducing cellular responsiveness to MIF. Experiments are proposed to test the possibility of developing MIF as a biomarker and MIF inhibitors as chemotherapy drugs. MIF levels and MIF-regulated pro-tumorigenic activities should be monitored *in vitro*, *in vivo* and in human trials.

Current cancer treatment has encountered many difficulties and MIF might be the key to solve these issues. 1) The heterogeneity in genetic mutations, protein expressions and tumorigenic mechanisms for different types of cancer makes it impossible generate a widely applicable prognosticator or a common treatment. However, MIF might be a promising target protein because a high level of MIF is a feature shared by all types of cancer with few exceptions. 2) Some patients have developed resistance to the existent chemotherapy drugs, so there is an urgent need for a novel medicine. MIF antagonists have great therapeutic value. 3) Chemotherapy, one of the most common cancer treatments, relies on cytotoxic substances that prevent cancer cells from mitosis, but at the same time, upset the proliferation of normal cells for tissue repair and growth. This results in nausea, hair loss, anemia, etc. MIF inhibitors, however, only target MIF functioning, while other metabolic activities are carried out as usual.

MIF antagonists might need to be administered along with other cancer treatment. If MIF antagonists alone can effectively contain cancer development, then therapies that cause problematic side effects will no longer

be needed. Even if MIF inhibitors are found to be not effective in cancer treatment, they might at least enhance the effects of other therapies by suppressing the MIF that helps cancer cells to grow under adverse situations and avoid immune surveillance.

Currently, the common method to determine the levels of serum MIF is ELISA. Although it has been made commercially available in HIV and allergy detection, this assay takes about 24 hours to complete and costs hundreds if not thousands of dollars. A quicker, easier and cheaper test without compromising the accuracy is critical to establishing MIF as a prognosticator.

One of the possible side effects of anti-MIF chemotherapy of is that since MIF induces inflammation, the ability of an individual to deal with inflammation and cell repair can be restrained. To tackle this problem, specific delivery of MIF inhibitors should be further studied.

MIF is involved in pathogenesis of multiple diseases besides cancer. It has been associated with sepsis, pneumonia, diabetes, rheumatoid arthritis, inflammatory bowel disease, acute respiratory distress syndrome and acute pancreatitis, some of which can be alleviated via drugs but lack a cure. (Al-Abed & VanBatten, 2011; Zhou et al., 2018). Although further studies are needed to confirm which MIF antagonist is the best for different diseases, the results from the hypothetical experiment in this essay have promising implications for quite a few diseases related to MIF overexpression. Once the technology is mature enough to use MIF as a biomarker and potential therapeutic target for cancer, hundreds of thousands of patients, in addition to cancer patients, will benefit.

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Impact of Entrepreneurial Activities and Innovation on the United States' Economy from 2011 to 2018

Using Statistics from the Global Entrepreneurship Monitor, Global Innovation Index, Bureau of Economic Analysis, Bureau of Labor Statistics, and the World Bank

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Abstract

This research uses data from the Global Entrepreneurship Monitor (GEM), Global Innovation Index (GII), Bureau of Economic Analysis (BEA), Bureau of Labor Statistics (BLS), and the World Bank from 2011 to 2018, covering nine different indices to measure entrepreneurial activities (Perceived Opportunity Rate, PO; Entrepreneurial Intention Rate, EI; Total early-stage Entrepreneurial Activities Rate, TEA), Innovation (Innovation Rate, IR; Global Innovation Index, GII), and the national economy (Gross Domestic Product, GDP; Annual GDP Growth Rate, GDP G.; Unemployment Rate, UR; and Gini Coefficient, Gini). Using Pearson's correlation analysis, the researcher found very strong positive correlation ($0.75 \leq r < 1$) between PO and GDP; moderate correlation ($0.25 \leq r < 0.50$) between GDP and IR; very strong negative correlation ($0.75 \leq |r| < 1$) between PO and UR; strong negative correlation ($0.50 \leq |r| < 0.75$) between IR and UR; weak correlation ($0.10 \leq r < 0.25$) between GII and PO. The results support Wong et al. (2005) that not all entrepreneurial activities benefit innovation, and the impact

of entrepreneurial activities and innovation on the national economy might be less significant than previously believed. For governors and entrepreneurs, this research shows that the impact of entrepreneurial activities and innovation on the economy might be overestimated. For scholars, this research questions a common belief that entrepreneurship and innovation are the engines of the economy. This research can improve by using a more compelling reason for the year range, analyzing data from multiple countries with shared characteristics, and using datasets that show significant correlation with others.

Key Words: Entrepreneurship; Innovation; Economy; Global Entrepreneurship Monitor; Global Innovation Index; Bureau of Economic Analysis; Bureau of Labor Statistics; World Bank; United States.

1. Introduction

Ever since Joseph Schumpeter (1934, p.66) proposed that entrepreneurial activities and the introduction of new means for production stimulate economic growth, the business world has been fascinated by the whole notion of innovation. Later, after Bower et al. (1995) introduced the concept of “disruptive innovation”, scholars and governors established a firm belief that innovation can, or at least has the potential to, have a profound impact on economic growth (increase in national productivity) and economic development (improvement in citizens’ living standard). Several key concepts are pervasive in this research and, to avoid misconceptions, the definitions and controversies among the definitions are examined.

One of the earliest definitions of innovation comes from Schumpeter, who defines product innovation as “the introduction of a new good . . . or a new quality of a good” (1983). Similarly, others define innovation as “the intersection of invention and insight, leading to the creation of social and economic value” (*Council on Competitiveness*, 2005) and “the blend of invention, insight and entrepreneurship that launches growth industries, generates new value and creates high value jobs” (*Business Council of New York State*, 2006). The definitions above share a common ground—innovation is “the extraction of economic value from novel activities” (*Innovation Vital Signs Project*, 2007). However, some scholars argue that innovation does not have to extract “economic value” and can merely be “inventions that are put in use” (Bozeman and Link, 1983). Thus, in this paper, innovation refers to the implementation of novel ideas regardless of economic values.

Although there is a strong association between innovation and entrepreneurship, the terms are not interchangeable. While innovation primarily

focuses on implementing novel ideas, entrepreneurship refers to the ability to perceive opportunities and take action on the perception (Link and Siegel, 2007, p. 3). Other definitions are mostly similar, but they typically take into account the risks involved in entrepreneurship since many scholars believe that risks are inherent in entrepreneurship. Therefore, adding to Link and Siegel's definition, entrepreneurship is the ability to perceive and act on opportunities while undertaking the risks involved.

Throughout this research, other terminologies describing national economic development level might arise frequently. According to the *Global Entrepreneurship Monitor (GEM)*, there are three levels of economic development: factor-driven economies, efficiency-driven economies, and innovation-driven economies. Factor-driven economies are the least developed, while innovation-driven economies are the most developed. Factor-driven economies are characterized by their "subsistence agriculture and extraction businesses, with a heavy reliance on (unskilled) labor and natural resources" (*Global Entrepreneurship Research Association*). For efficiency-driven economies, they are "increasingly competitive, with more-efficient production processes and increased product quality" (*Global Entrepreneurship Research Association*). As the most developed economic level, innovation-driven economies' "businesses are more knowledge-intensive, and the service sector expands" (*Global Entrepreneurship Research Association*).

In this research, the investigator will use binomial correlation coefficients (Pearson's correlation coefficient), a quantitative method, to identify the extent of the correlation between entrepreneurship, innovation, and economic performance. Entrepreneurship is measured by *GEM's* Perceived Opportunity Rate (*PO*), Entrepreneurial Intention Rate (*EI*), and Total early-stage Entrepreneurial Activities Rate (*TEA*). Innovation is measured using *GEM's* Innovation Rate (*IR*) and Global Innovation Index (*GII*) from an organization named *Global Innovation Index*. National economic performance is measured using the Annual Gross Domestic Product (*GDP*), Annual GDP Growth Rate (*GDP G.*), Unemployment Rate (*UR*), and Gini coefficient (*Gini*). Ultimately, the investigator aims to answer the following question: to what extent do entrepreneurship and innovation impact the US economy?

The second section of the paper focuses on the findings and the blank space in the existing literature. It first discusses the impact brought by external factors on entrepreneurship, innovation, and economy. Then, to narrow the context, the section discusses the relationship between entrepreneurship, innovation, and the US national economy. Also, the section identifies the need for conducting further research on this topic. The third section introduces the methodology, including how different organizations obtain their

data while explaining their definition of the indicators and indices. In the same section, the investigator will give a detailed account of the quantitative analysis method. Penultimately, the fourth section provides the results and the analysis while evaluating the research by discussing the shortcomings of and possible improvements for the research. Also, the section explains the possible implications of the research. Finally, the conclusion section summarizes the key research findings and concludes the research paper.

2. Literature Review

In this section of the paper, existing literature will be discussed, analyzed, and evaluated in order to identify the need for additional research. This research examined journals such as *Entrepreneurship Theory and Practice*, *Technological Forecasting and Social Change*, *Small Business Economics*, and the *International Small Business Journal: Researching Entrepreneurship*.

There are three parts to the literature review: the first part discusses the general research that has been done related to innovation, entrepreneurship, and national economy in order to provide some broad context. This section includes the impact of factors like political factors and societal factor on entrepreneurship and innovation. To narrow the topic, the second section provides a detailed discussion on the relationship between entrepreneurship, innovation, and the national economy. The last section discusses the limitations of existing research, and some areas that have not been researched will be discussed in order to show the necessity of conducting additional research.

2.1 General Discussions

The existing literature investigated a myriad of factors that can influence entrepreneurial, innovation, and national economy (Hechavarría, 2016; Alon et al., 2016; Rusu and Roman, 2017; Hechavarría and Ingram, 2018; Estrin and Mickiewicz, 2011). For entrepreneurship and innovation, the impact of the external environment will be discussed to provide a general context. More background context on the national economy will be provided in the second section (relationship between entrepreneurship, innovation, and national economy).

Rusu and Roman (2017) researched the determinants of entrepreneurial activities in the European Union. Their research evaluated the relationships between 14 indices (or indicators) from the GEM database and the *World Bank Databank* with Total early-stage entrepreneurship activities (*TEA*, from GEM), which is a common index used to measure entrepreneurial activities.

The 14 indices were categorized as measures of “macroeconomic stability,” measures of “individual factors,” and measures of “business-environment related factors.” In short, the researchers concluded that all three categories of measurements exert a considerable amount of influence on *TEA*.

Out of all the indices, Rusu and Roman found that “Total Tax Rate,” “Fear of Failure Rate,” “Entrepreneurial Intention Rate,” “Cost of Business Start-up Procedures,” and “number of procedures needed for establishing a new firm” have the strongest influence on *TEA*. In terms of the categories, “individual factors” have the strongest correlation with *TEA*. However, according to Rusu and Roman, “only 50% from the variation of the total entrepreneurship rate is explained by the variation of the considered variables,” suggesting that there are many other variables influencing *TEA*.

Another research topic that arose in the recent data investigated gender equality issues within a business context (Hechavarría & Ingram, 2018). Hechavarría and Ingram (2018) studied the impact of the entrepreneurial ecosystem on male and female venturing prevalence rates. Using data from the World Bank Development Indicators and the GEM of 75 countries between 2001 and 2014, the researchers computed for the bivariate correlation between different datasets. In contrary to the researchers’ hypotheses, the results show that “financial policies, government programs, and educational support have no impact on female and male entrepreneurial prevalence rates.” Nevertheless, cultural forces, in general, do have a stronger influence on females than males in a positive way (Hechavarría and Ingram, 2017; Estrin and Mickiewicz, 2011).

Additionally, the full data sample (75 countries, including innovation- and efficiency-driven economies) demonstrates that government programs have a profound negative impact on the male venturing rate. On innovation-driven economies specifically, the female venturing rate decreases significantly. This research result questions the efficacy of government programs in fostering entrepreneurial activities. Hechavarría and Ingram believe that male entrepreneurs are “stymied by bureaucracy associated with governmental support programs”. Furthermore, since the majority of government programs focus on “underrepresented groups,” male entrepreneurs do not experience as many benefits. On the other hand, the reason why government programs negatively influence female entrepreneurship in innovation-driven economies still remains unclear.

Another research by Sarfaraz, Faghih, and Majd (2014) questioned the relationship between female entrepreneurship with gender equality by comparing the Gender Development Index (GDI) from the United Nations and “different stages of women entrepreneurial activity” from the GEM. Through their bivariate correlation analysis, they found no notable relationship

between the two sets of variables, disputing their hypothesis that increases in GDI could lead to better female entrepreneurial activities. In fact, the researchers state that the two indices might be independent of each other (in the considered countries and dataset).

2.2 Relationships Between Innovation, Entrepreneurship, and National Economy

Entrepreneurship and innovation are two highly related concepts that are not interchangeable. As mentioned previously, innovation is the implementation of novel ideas with or without economic values, and entrepreneurship is the ability to perceive and act on opportunities while undertaking the risks involved. On the other hand, the national economy is the economic performance of a given nation.

Currently, many existing studies claim that the three variables—innovation, entrepreneurship, and national economy—exert a positive influence on each other (Galindo, Méndez, 2014; Van Vauuren, Alemayehu, 2018; Audretsch, Keilbach, 2008). For instance, some claim that entrepreneurship plays an essential role in contributing to the economy. Scholars consider entrepreneurship as the “main engine for economic growth” (Audretsch and Keilbach, 2008; Rusu and Roman, 2017; Zvavahera et al., 2018), and it is also the main contributor to innovations and job opportunities (Rusu and Roman, 2017). For innovation, Pech (2015) claims that “it has been demonstrated . . . during the last one and a half centuries that . . . new ideas (also known as innovations), particularly disruptive ideas, can lead to fundamental changes in products and services upon which commercial markets thrive”, suggesting that innovation certainly exerts a large influence on entrepreneurship and national economy, but that it also influences areas beyond entrepreneurship and national economy.

Galindo and Méndez (2014) researched 13 developed countries and conducted empirical analysis of the interconnection between innovation, entrepreneurship, and national economy. Their research claims that innovation and entrepreneurial activities improve the national economy. As the latter strengthens, it enhances innovation and entrepreneurial activities.

Van Vauuren and Alemayehu’s (2018) research came to a similar conclusion. Using statistics from GEM, Van Vauuren and Alemayehu analyzed the correlation between *GDP*, GEM’s Perceive Opportunity Rate (*PO*), Entrepreneurial Intention Rate (*EI*), and Total early-stage Entrepreneurial Activities (*TEA*). The research found that there is a positive correlation between entrepreneurship and economy despite the national development level (innovation-driven or efficiency-driven, factor-driven economies were not included in

the research). Nonetheless, entrepreneurial activities in innovation-driven economies do have a higher correlation with national economy relative to efficiency-driven economies.

Feki and Mnif (2016) investigated the relationship between entrepreneurship, technological innovation, and economic growth. They gathered seven years of data from 35 developing countries and found that innovation has a positive influence on economic growth. Specifically, innovation negatively influences economic growth in the short term but stimulates growth in the long term. According to Feki and Mnif, innovation negatively affects economic growth in the short term but exerts a positive influence in the long term because technological advancements often lead to improved machinery, which increases production efficiency (requires less input to produce the same or more outputs). This effect is particularly obvious in developing countries since the technology level is not as advanced. Thus, increased productivity leads to a decreased job opportunity, causing a dip in economic growth. However, in the long term, increased productivity stimulates growth.

Peris-Ortiz et al. (2018) explored the indirect benefits of entrepreneurship. The research found that more-developed economies generate more high-quality entrepreneurship, which is characterized by being more innovative. This is because more-developed economies already grant entrepreneurs enough recognition, which encourages entrepreneurial activities. In addition to high recognition for entrepreneurs, many other factors in a developed economy also advocate, encourage, and embrace entrepreneurship, encouraging the emergence of quality entrepreneurial activities.

2.3 Necessity Research

Although past research explored numerous fields, there are still many areas of opportunity. This can either be created by improvements in past research's methodology or an area that has not been explored excessively.

In terms of improvements in methodology, a few studies discussed in the previous sections can be improved in order to achieve a higher degree of precision and accuracy. Although Galindo and Mendez's research is compelling, their measurement of "innovation" is somewhat inaccurate. Galindo and Mendez measure innovation by the "number of patent issues" (Galindo and Mendez, 2014). However, the "number of patent issues" is not a comprehensive measure of the level of innovation since the number patents issued does not directly influence the impact brought by the innovations, making its research finding inconclusive. In addition to a "number of patent issues," the researchers could have included measures of the influences and changes brought by the patents. Therefore, this attempts to provide a more

comprehensive measure of innovation by using two different innovation indices: Innovation Rate (*IR*) and Global Innovation Index (*GII*).

Even though Van Vauuren and Alemayehu provided a solid foundation for my research, they could have measured the national economy more thoroughly. Van Vauuren and Alemayehu's research only used GDP to reflect the level of economic development, which only reflects the general performance of the national economy. As recommended by the researchers, my research will incorporate more measures of national economic development by using indicators like Unemployment Rate, Gini coefficient, and GDP growth rate, in order to provide a more comprehensive analysis of the relationship between entrepreneurship, innovation, and economic development.

Similarly, Feki and Mnif offered valuable information about the relationship between entrepreneurship, innovation, and the economy. Nonetheless, the research only looked into developing countries' data from 2004 to 2011. Despite the fact that the data is somewhat outdated, the research only targets developing countries specifically. Hence, in my study, the research will focus on the US, a developed country, specifically. On top of that, in the data analysis, Feki and Mnif used methodologies (such as linear regression) and different datasets (such as rate of investment in physical capital, level of consumer prices, rate of exports plus imports to GDP). Thus, in my research, I will use different datasets to analyze the correlations between entrepreneurship, innovation, and the national economy.

3. Methodology

This research uses a quantitative approach to analyze and evaluate the relationship between entrepreneurial activities, innovation, and the national economy. To ensure the accuracy, precision, and reliability of data, all statistics are collected from the Global Entrepreneurship Monitor (GEM), U.S. Bureau of Economic Analysis (BEA), U.S. Bureau of Labor Statistics (BLS), the World Bank (WB), and the Global Innovation Index (GII).

3.1 Data

Each organization mentioned uses a unique approach to gather information and formulate the index (data). The methodology for each organization will be introduced.

3.1.1 Measures of Entrepreneurship and Innovation

Measures of entrepreneurship and innovation come from two organizations: the GEM and the GII. The GEM collects data using the "Adult Population

Survey (APS)” and “National Expert Surveys (NES)”. The two components are complementary of each other and create a relatively complete image of a nation’s entrepreneurial condition. Then, after data experts scrutinize the data and confirm the validity of it, the GEM publishes the data. As a result, the APS and the NES formulate indicators for “Entrepreneurial Behavior and Attitudes” and “Entrepreneurial Framework Condition,” respectively (Global Entrepreneurship Research Association). In this research, Perceived Opportunity Rate (PO), Entrepreneurial Intention (EI), and Total early-stage Entrepreneurial Activities (TEA) are used to measure entrepreneurial activities. First, the PO refers to the “percentage of 18–64 population (individuals in any stage of entrepreneurial activities excluded) who see good opportunities to start a firm in the area where they live.” Second, the EI is defined as “percentage of 18–64 population (individuals in any stage of entrepreneurial activities excluded) who are latent entrepreneurs and who intend to start a business within three years.” Last, the TEA refers to the “percentage of 18–64 population who are either a nascent entrepreneur or owner-manager of a new business”. In order to measure innovation, the Innovation Rate from the GEM is also being used. According to the GEM, Innovation Rate is the “percentage of those involved in TEA who indicate that their product or service is new to at least some customers AND that few/no businesses offer the same product.” Thus, the four indices are used to measure entrepreneurship and innovation.

In addition to the Innovation Rate from the GEM, this research also uses the Global Innovation Index (GII) from the GII. The GII computes its index using the Innovation Input Sub-Index and the Innovation Output Sub-Index—two sub-indices that measure different aspects of innovation. The Innovation Input Sub-Index focuses on factors that made innovation possible: “institution, human capital and research, infrastructure, market sophistication, and business sophistication” (Cornell et al., 2019). Then, the mean values of the five factors are computed, creating the Innovation Input Sub-Index. On the other hand, the Innovation Output Sub-Index relies on the “actual evidence of innovation outputs” and is measured by “knowledge and technology output” and “creative outputs”. Again, the mean value of “knowledge and technology output” and “creative outputs” are computed, generating the Innovation Output Sub-Index. Finally, the mean of the Innovation Input Sub-Index and the Innovation Output Sub-Index generates the *GII* (Cornell et al., 2019).

3.1.2 Measures of National Economy

The research also uses the Unemployment Rate, Gross Domestic Product (GDP), GDP Annual Growth Rate, and Income Inequality Gini Coefficient

(or Gini Index) from the BLS, the World Bank, the BEA, and U.S. Census, respectively. The BLS classifies people “as unemployed if they do not have a job, have actively looked for work in the prior four weeks, and are currently available for work” (Bureau of Labor Statistics). Therefore, the Unemployment Rate measures the percentage of people who are defined as “unemployed”. GDP is the “value of goods and services produced in the United States” (Bureau of Economic Analysis). However, the World Bank did not specify the methodology for their calculation/ estimation. On the other hand, the *GDP Annual Growth Rate* is computed based on the reported *GDP* by using *GDP* growth (most recent year minus the previous year) and divide the value by the *GDP* of the previous year. Since the BEA reports *GDP Annual Growth Rate* quarterly, the investigator has compiled the quarterly growth rate and computed the average of the quarterly growth rate to obtain the Annual *GDP Growth Rate*. Last, the Gini coefficient is an indication of income inequality, and the values range between 0 to 1. A coefficient of 0 represents a perfectly balanced distribution, in which everyone receives the same amount of income. In contrast, a coefficient of 1 indicates a perfectly imbalanced distribution, whereby exactly one person receives all the income while others earn nothing (U.S. Census Bureau, 2016).

Overall, indices and indicators are categorized into three groups: measures of entrepreneurship, measures of innovation, and measures of the national economy. *PO*, *EI*, and *TEA* are measures of entrepreneurship, *IR* and *GII* are measures of innovation, and Annual *GDP*, *GDP Growth Rate (GDP G.)*, Unemployment Rate (*UR*), and Gini coefficient (*Gini*) are measures of economic performance. By categorizing indices and indicators to measure the performance of a particular field (for instance, national economy), the investigator can measure entrepreneurship, innovation, and the national economy more comprehensively, which improves the accuracy of the research.

3.2 Method

This research uses Pearson’s correlation coefficient to analyze the correlation between different datasets. Some scholars argue that only correlations above 0.80 or 0.90 can be considered as “strong” (Verbeek, 2008). However, others believe that multicollinearity—phenomena where one variable in a multiple variable regression model can be predicted with a substantial degree of accuracy—exists when the correlation is above 0.70 or 0.80 (Anderson et al., 2011; Bryman and Cramer, 2002). Therefore, in this research, correlations equal to or above 0.75 are defined as a very strong positive correlation ($0.75 \leq r \leq 1$). Correlations below 0.75 but greater than or equal to 0.50 are

defined as a strong positive correlation ($0.50 \leq r < 0.75$). A moderate positive correlation exists when the coefficient is below 0.50 but is greater or equal to 0.25 ($0.25 \leq r < 0.50$). Coefficients below 0.25 but greater than 0.10 ($0.10 \leq r < 0.25$) is considered as a weak correlation. Coefficients below 0.10 ($0 < r < 0.10$) show little to no correlation.

For negative correlations, correlations that are above -1 but below or equal to -0.75 represent a very strong negative correlation ($-1 \leq r \leq -0.75$). Correlations above -0.75 but below or equal to -0.50 show a strong negative correlation ($-0.75 < r \leq -0.50$). Correlations above -0.50 but below or equal to -0.25 demonstrate a moderate negative correlation ($-0.50 < r \leq -0.25$). Correlations above -0.25 but below or equal to -0.10 are considered weak negative correlations ($-0.25 \leq r < -0.10$). Correlations above -0.10 and below or equal to 0 show little to no correlation.

In this analysis, p -values below 0.05 level are considered as significant ($p < 0.05$), and p -values above 0.05 level is considered as insignificant, which means they do not indicate anything about the two sets of data. Meanwhile, based upon past research (Sarfaraz et al., 2014; Hechavarría and Ingram, 2018; Rusu and Roman, 2017; Van Vuuren and Alemayehu, 2018), in the analysis, all data are kept in three-digit values.

3.3 Hypothesis

Hypothesis 1: Economy will positively influence entrepreneurial activities and vice versa.

This hypothesis is backed by numerous past studies in which the researchers investigated the relationship between economy and entrepreneurship (Galindo and Méndez, 2014; Van Vuuren and Alemayehu, 2018; Audretsch and Keilbach, 2008). Most studies that support *Hypothesis 1* argue that entrepreneurship is the driver of economic growth, and that economic growth leads to a better economic environment that fosters entrepreneurial activities. In this research, measures of the national economy include Gross Domestic Product (*GDP*), Annual GDP Growth Rate (*GDP G.*), Unemployment Rate (*UR*), and Gini coefficient (*Gini*), and measures of entrepreneurship include GEM's Perceive Opportunity Rate (*PO*), Entrepreneurial Intention Rate (*EI*), and Total early-stage Entrepreneurial Activities Rate (*TEA*).

If *Hypothesis 1* is true, *GDP*, Annual *GDP* Growth Rate, and *Gini* coefficient will have a positive correlation with measures of entrepreneurial activities (Perceive Opportunity Rate, Entrepreneurial Intention Rate, and Total early-stage Entrepreneurial Activities). Unemployment Rate, on the

other hand, will have a negative correlation with measures of entrepreneurial activities. Numerous past studies suggest that entrepreneurial activities are strongly correlated with the economy. Thus, this research presumes that all measures of the economy will at least have a moderate correlation with the economy ($0.50 \leq r$).

Hypothesis 2: Economy will positively influence innovation, and vice versa.

Even though entrepreneurial activities can stimulate innovation, extant literature has found the direct benefits of a strong economy on innovation. Innovation, especially technological innovation, brings new products that aim to address the issues the world is facing. This includes new methods of production and new ways of distributing goods, which increases productivity, creates job opportunities, and improves life quality (Gerguri and Ramadani, 2010). These changes improve the economic condition, which leads to a more favorable market condition and stimulates more innovation. Therefore, the researcher believes that innovation and the national economy will have a positive correlation.

If *Hypothesis 2* is true, *GDP*, Annual *GDP* Growth Rate, and *Gini* coefficient will be positively correlated with measures of innovation (*IR* and *GII*), while Unemployment Rate (*UR*) will be negatively correlated with measures of innovation. Besides, according to past research (Gerguri and Ramadani, 2010; Feki and Mnif, 2016), there should at least be a moderate correlation (positive or negative) between national economy and innovation ($0.50 \leq r$).

Hypothesis 3: Entrepreneurial activities will exert a positive influence on innovation and vice versa.

Hypothesis 3 is based on Joseph Schumpeter's *The Theory of Economic Development* (1934), which claims that bringing in innovation is in the nature of entrepreneurship. According to Schumpeter's *Innovation Theory of Entrepreneurship*, entrepreneurship is the direct result of innovation, and entrepreneurs can survive and retain a competitive advantage if they introduce innovation. Furthermore, empirical analysis from Audretsch and Keilbach (2008) also suggested that entrepreneurial investment brings "significant and strongly positive impact on . . . economic development," providing modern empirical analysis to support Schumpeter's *Innovation Theory of Entrepreneurship*.

Therefore, if *Hypothesis 3* is valid, measures of entrepreneurial activities (Perceive Opportunity Rate, *PO*; Entrepreneurial Intention Rate, *EI*; and

Total early-stage Entrepreneurial Activities Rate, *TEA*) will be positively correlated with measures of innovation (Innovation Rate, *IR*, and Global Innovation Index, *GII*) and there will at least be a moderate correlation between the two measures ($0.25 \leq r$).

4. Results

4.1 Innovation, Entrepreneurship, and National Economy

Table 1 shows the descriptive statistics of variables and Table 2 is the correlation matrix of variables.

According to Table 2, *GDP* (Gross Domestic Product) has a very strong positive correlation ($0.75 < r \leq 1$) with *PO* (Perceive Opportunity Rate) at 0.01 level ($p < 0.01$). Along with *PO*, *IR* (Innovation Rate) also has a significant moderate positive correlation ($0.25 \leq r < 0.50$) with *GDP* at 0.05 level ($p < 0.05$). Although most other variables at least demonstrated a moderate correlation (positive or negative) with *GDP* (except *EI*, Entrepreneurial Intention Rate, and *GII*, Global Innovation Index), their correlations are insignificant at both 0.05 level ($p < 0.05$) and 0.01 level ($p < 0.01$). Therefore, no valid observations can be made from this data.

GDP G. (Annual GDP Growth Rate) appears to have a moderate positive correlation ($0.25 \leq r < 0.50$) with most variables, but the correlations are all insignificant at both levels. *UR* (Unemployment Rate) has a significant, very strong negative correlation ($-1 < r \leq -0.75$) with *PO* at 0.01 level ($p < 0.01$), with a correlation coefficient (r) of -0.887. Similarly, *UR* also showed a significantly strong negative correlation ($-0.75 < r \leq 0.75$) at 0.01 level ($p < 0.01$) with *IR* (Innovation Rate). *Gini* (Gini coefficient) has no significant correlation

Table 1. *Descriptive statistics of variables*

Variables	Mean	Median	Min.	Max.	S.D.	Skewness	Kurtosis
<i>GDP</i>	17869.021	17870.525	15542.58	20494.1	1683.232	0.174	-0.914
<i>GDP G.</i>	2.254	2.33	1.53	2.93	0.54	-0.103	-1.514
<i>UR</i>	5.991	5.72	3.88	8.93	1.963	0.342	-1.575
<i>Gini</i>	0.48	0.48	0.477	0.482	0.002	-0.342	-1.69
<i>PO</i>	51.884	49.005	36.25	69.83	11.045	0.407	-0.539
<i>EI</i>	12.31	12.165	10.92	14.54	1.027	1.441	3.9
<i>TEA</i>	13.183	12.785	11.88	15.59	1.161	1.362	2.147
<i>IR</i>	35.2	35.085	33.52	37.1	1.389	0.177	-2.007
<i>GII</i>	60.517	60.2	59.8	61.4	0.703	0.74	-1.815

with any variables on either level. *PO* (Perceive Opportunity Rate) has a significant weak positive correlation ($0.10 \leq r < 0.25$) with *GII* (Global Innovation Index) at the 0.05 level ($p < 0.05$). Correlations between *Gini* and other variables appear to be insignificant at both levels. Although insignificant, the correlation between *TEA* (Total early-stage Entrepreneurial Activities), and both innovation indices, *IR* (Innovation Rate) and *GII* (Global Innovation Index), appear to have a negative correlation. However, since the correlations are insignificant, no reasonable explanation can be given with a sufficient amount of evidence. *IR* (Innovation Rate) appears to have a moderate correlation with the *GII* (Global Innovation Index). However, the correlation is also insignificant at both levels.

Overall, neither the measures of entrepreneurship nor the measures of innovation demonstrated significant correlations with measures of the national economy, and these results are also backed by past research. According to Rusu and Roman's (2017) research, the impact of entrepreneurial activities might have been overestimated. Findings from Rusu and Roman's research suggest that other variables, including measures of macroeconomic conditions and measures of individuals' attitudes, can only explain around 50% of the variation in total entrepreneurship rate, suggesting that entrepreneurial activities and national economy are not strongly correlated. This occurs because entrepreneurial activities are only one of the propellants for economic growth and economic development. Although entrepreneurial activities might play a larger role than other factors, its impact is still limited. Similarly, innovation also has a weak correlation with national economy

Table 2. Correlation matrix of variables

	GDP	GDP G.	UR	Gini	PO	EI	TEA	IR	GII
GDP	1								
GDP G.	0.576	1							
UR	-0.954	-0.451	1						
Gini	0.707	0.012	-0.67	1					
PO	0.957**	0.469	-0.887**	0.793	1				
EI	0.479	0.402	-0.423	0.502	0.512	1			
TEA	0.654	0.489	-0.465	0.413	0.78	0.229	1		
IR	0.376*	0.115	-0.605**	0.517	0.291	0.263	-0.134	1	
GII	0.111	-0.648	-0.383	0.580	0.178*	0.47	-0.315	0.541	1

because most innovation does not translate into economic growth or economic development.

Innovation also has a limited impact on entrepreneurial activities and vice versa. This result confirms the study by Wong et al. (2005), which claims that only limited entrepreneurial activities contribute to innovation. Most entrepreneurial activities are not involved in the research and development process (R&D), and only those startups involved in the R&D process can have a greater contribution to innovation. Some might argue that startups tend to invest the most in the R&D process, which is certainly valid for some industries. However, in most cases, entrepreneurial activities can simply be opening a convenience store, which requires little to no R&D.

4.2 Assessing Hypothesis

Hypothesis 1: Economy will positively influence entrepreneurship and vice versa.

Previously, the investigator presumed that economy (*GDP*, *GDP G.*, *UR*, and *Gini*) and entrepreneurship (*PO*, *EI*, and *TEA*) would be positively correlated and that there would be a strong correlation between the variables. However, the result shows that only the *PO* (Perceive Opportunity Rate) and *GDP* (Gross Domestic Product), *PO* (Perceive Opportunity) and *UR* (Unemployment Rate) are strongly correlated with an acceptable level of error ($p < 0.05$). Since two significant very strong correlations exist, *Hypothesis 1* is partially verified.

Hypothesis 2: Economy will positively influence innovation and vice versa.

Hypothesis 2 presumes that economy will be strongly and positively correlated with innovation. However, only *IR* (Innovation Rate) and *GDP* (Gross Domestic Product) and *IR* and *UR* (Unemployment Rate) showed significant correlation ($p < 0.05$). Hence, *Hypothesis 2* is partially verified.

Hypothesis 3: Entrepreneurial activities will exert a positive influence on innovation and vice versa.

This hypothesis presumed a strong positive correlation between innovation rate and entrepreneurial activities. However, only *PO* (Perceive Opportunity Rate) and *GII* (Global Innovation Index) showed a significant weak correlation ($0.10 \leq r < 0.25$). Other groups of data did not show any strong

correlation, and no other pairs of data showed a significant correlation. Thus, *Hypothesis 3* is refuted.

5. Conclusion and Discussion

The extant literature explored the correlation between entrepreneurship, innovation, and national economy, and this research contributes to the existing literature by providing a more comprehensive analysis of the variables. Specifically, this research used more comprehensive measures of innovation (Galindo and Mendez, 2014) and national economy (Van Vauuren and Alemayehu, 2018), while using the most recent available data (Feki and Mnif, 2016).

This research uses data from the Global Entrepreneurship Monitor (GEM), Global Innovation Index (GII), Bureau of Economic Analysis (BEA), Bureau of Labor Statistics (BLS), and the World Bank from 2011 to 2017. Overall, the research covers nine different indices to measure entrepreneurial activities, innovation, and the national economy. Measures of entrepreneurial activities include *PO* (Perceive Opportunity Rate), *EI* (Entrepreneurial Intention), and *TEA* (Total early-stage Entrepreneurial Activities); measures of innovation include *IR* (Innovation Rate) and *GII* (Global Innovation Index); measures of national economy include *GDP* (Gross Domestic Product), *GDP G.* (Annual GDP Growth Rate), *UR* (Unemployment Rate), and *Gini* (Gini coefficient). By using Pearson's correlation analysis, the researcher was able to identify the relationship between different datasets.

As a result, this research suggests that the correlation between entrepreneurial activities, innovation, and the national economy might be limited. As Wong et al. (2005) suggest, entrepreneurial activities and innovation have a relatively low correlation because very few entrepreneurial activities translate into innovation, and innovation does not always translate into economic growth or economic development.

As Rusu and Roman (2017) suggest, for entrepreneurial activities and the national economy, entrepreneurial activity is not the only factor that contributes to the national economy (especially the *GDP*); many other factors are also involved. Therefore, the correlation between entrepreneurial activities and the national economy is also weaker than expected.

In terms of the implications of the research, the effects of this research are limited. The results did show some significant correlations, but only a limited number of datasets showed a significant correlation with other datasets. The findings of this research might suggest that entrepreneurial activities and innovation might not have as much impact on the national economy as the extant literature has argued. Unfortunately, this argument cannot be made with sufficient supporting evidence since most correlations

were proven to be insignificant. This makes the result less important to governors and entrepreneurs because this research does not provide a new perspective on the relationship between entrepreneurial activities, innovation, and national economy, nor do the results provide highly convincing data to make further arguments.

For scholars, this research acts as supporting evidence of the extant literature. Numerous extant studies investigated the relationship between entrepreneurial activities, innovation, and national economy, and this research did come to a similar conclusion: entrepreneurial activities and innovation do have at least a considerable influence on the national economy, but their influence may be weaker than expected.

There are several limitations to this research. First, the researcher could have found a more compelling reason for choosing the years of research. This research used data from 2011 to 2017 since this choice maximizes the available datasets. If the time period extends to 2010, certain data will be missing. Future scholars can select data year ranges based on the significant events that occur—for instance, presidencies, significant changes in government policy, or different stages of the business cycle. This change could limit random errors within the data since all of the events above will exert a considerable amount of influence on the data, reducing the accuracy and precision of the results.

Second, the year choice also creates another error because *GII* (Global Innovation Index) was only founded in 2013, suggesting that it is missing two years of data (2011 and 2012), which affects the research by creating less accurate correlations. To avoid this, future scholars should only attempt to use complete datasets for analysis.

Third, this research only examined the US, which only reflects the situation in the US. Since this research only uses data from the US, national market environment, culture (social norms), and government policies in the US will influence the data significantly. The findings of the research, including the extent and significance of the correlation, do little to reflect the influence of entrepreneurial activities and innovation on the national economy in other countries. In order to assess the impact of entrepreneurial activities and innovation on the national economy, researchers should focus on a particular group of countries—it can be categorized by their geographic location, stage of development, or any other classifications—and assess the impact of entrepreneurial activities and innovation within that particular context. Such results would be more compelling, and it would reflect the extent of the correlation between datasets more accurately.

Last, most of the results of this research are insignificant, which limits the impact of this research greatly. To maximize the impact of research,

future scholars should test a variety of different datasets before confirming the chosen datasets.

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Blockchain

Building a Path to Utopia

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Abstract

In this paper, the mathematical background of blockchain technology will be researched and implemented. Firstly, the security and anonymity of the blockchain is protected by carefully designed cryptographic methods. The mathematical theories and properties of these methods will be demonstrated, and the efficiency of different algorithms will be compared. The second part of this paper will show how the design of the blockchain helps people to reach an agreement when they are anonymous to each other. Beside concealing key information from each other, blockchain users should decide together and build a common ledger of transactions. Researchers use the “Byzantine-Tolerant problem” to analyze blockchain communication networks and to design specific consensus protocols to reach this goal. After exploring the theories of the blockchain, some applications of the blockchain will be introduced and I will build a student assessment system on the Ethereum using a smart contract. In the end, the prospects of blockchain technology and its challenges will be analyzed.

1. Introduction

Blockchain technology is used to build a decentralized and anonymous transaction system. With blockchain technology, people no longer need trusted third parties such as banks to build trust between each other [4]. Therefore,

they can save on transaction fees and make contracts more efficiently [6]. The first implementation of blockchain technology in finance is the Bitcoin, a cryptocurrency published in 2008. Over the years, the number of transactions on the Bitcoin platform has been increasing rapidly. Other applications of the blockchain, such as the smart contract, have also become famous around the world in the recent years.

The impressive properties and functions of the blockchain are supported by a strong mathematical background. Cryptographic tools protect sensitive data from adversaries, and consensus protocols maintain the efficiency of the decision-making in the sophisticated blockchain network. In the following sections, I will not only reveal these math theories and their applications separately, but also discuss how these elements coordinate with each other in blockchain systems.

2. Cryptographic Hash Function

The hash function is a function that we use to shorten our messages and conceal the important information in the plaintext message. With hash functions, messages of arbitrary length are digested into a fixed-length string. In this section, some basic features and algorithms in the hash function will be introduced, and the birthday attack on the hash function will be discussed.

2.1 The Elementary Features of Hash Functions

Since the purpose of the hash function is to transform messages, there are three necessary conditions to ensure the efficiency and security of hash functions:

1. Hash functions should be quickly calculated.
2. It is difficult to solve the equation $h(m) = y$ with a given y value. This feature is called “preimage resistant,” and the functions that fulfill this feature are called one-way functions because calculating the original function h is much easier than calculating the inverse function h^{-1} .
3. The pairs (m_1, m_2) that satisfy $h(m_1) = h(m_2)$ are rare, which means that it is hard to find two different messages that have the same hash value. This feature is called “collision-free.” [1]

To compress a message of arbitrary length into a 160-bit message, a simple hash function can be applied to achieve this goal. Firstly, 0s should be appended at the end of the original message so that the length of the modified message is a multiple of 160. Then, the modified message is divided

into some blocks of strings whose length is 160. These blocks can be added together using the exclusive-or operation and the final answer is a 160-bit string. Many hash functions use a process similar to the example above, excepting some modifications to satisfy the three necessary conditions of the hash functions. There are some classic examples of hash functions that will be demonstrated in the following sections.

2.2 MD5 and SHA-1

The MD5 and SHA-1 are two popular examples of hash functions. When we have the original message, the first thing we should do is to modify the original message as the input of the hash function. We usually use the Merkle-Damgard scheme to modify our message [3]. Supposed the final output of the hash function is a t -bits string. We can modify our message using the following steps [3]:

1. Add zeros to the left of the original message x so that the length of the new string x_0 is divisible by t .
2. Add t zeros on the right of x_0 , to get a new string x' .
3. Use y to represent the binary form of the length of x (the original string) and then add zeros at the end of y so that the length of y is divisible by $t-1$. Now y can be divided into several $(t-1)$ -bit substrings y_1, y_2, \dots, y_k .
4. For each $i=1, 2, \dots, k$, add a "1" to the left of y_i , and the new string after the operation is z .
5. Combine x' and z and get a string s whose length is divisible by t .

After the modification, we can then compute the SHA-1 algorithm. The SHA-1 hash function is a function with 160-bit outputs. The basic steps of applying the SHA-1 algorithm are listed in the following paragraph [1].

1. Convert the original message into a string with a length divisible by 512 using the Merkle-Damgard scheme. We can now divide the string into some blocks with 512 bits $s = X_1 X_2 \dots X_r$. We need a symbol ($b \ll n$) to represent a number b times 2^n in the binary representation and a function $f_t(B, C, D)$ which represents different binary operations under different values of t .
2. Initialize $H_0 = 67452301, H_1 = EFCDAB89, H_2 = 98BADCFE, H_3 = 10325476, H_4 = C3D2EIFQ$, each number represents an 8-digit hexadecimal number which is equal to a 32-bit binary string.
3. In each block $X_k, k=1, 2, 3, \dots, r$:

- 1) Divide the 512 bits into 16 small sections $W_0W_1\dots W_{15}$ and each section contains 32 bits. For $i=16,17,\dots,79$, set $W_i = (W_{i-3} \oplus W_{i-8} \oplus W_{i-14} \oplus W_{i-16}) \lll 1$.
- 2) Let $A = H_0, B = H_1, C = H_2, D = H_3, E = H_4$.
- 3) For $t = 0,1,\dots,79$, compute the following steps in succession:

$$T = (A \lll 5) + f_t(B, C, D) + E + W_t + K_t,$$

$$E = D, D = C, C = (B \lll 30), B = A, A = T$$

- 4) Let $H_0 = H_0 + A, H_1 = H_1 + B, H_2 = H_2 + C, H_3 = H_3 + D, H_4 = H_4 + E$.
4. Combine the final H_0, H_1, H_2, H_3, H_4 together and get the final hash value.

The core of the SHA-1 and the MD-5 algorithm is that we set an initial hash value vector G_0 and divide the string into substrings with the fixed length (160 bits in SHA-1) $X_1X_2\dots X_r$, and then calculate the next hash value G_i using a function $G_i = f(G_{i-1}, X_i)$. After r steps, we get the final hash value G_r [1].

Although MD5 and SHA-1 have the same process, the main difference between these two algorithms is that the output of MD5 is 128 bits rather than 160 bits, which makes the MD5 much less secure than the SHA-1. This statement will be analyzed in the following section on birthday attacks. Despite this difference, both MD5 and SHA-1 are good hash functions that satisfy the three properties listed in section 2.1: easy to calculate the hash, difficult to find the original message with given hash value, and “collision-free” [1].

2.3 Birthday Attack on Hash Functions

According to the third feature of hash functions, it is hard to find “collisions.” However, the hash functions will have occasional collisions and the collisions may undermine the security of hash functions. An efficient way of attacking the hash function, i.e. to find collisions in a relatively short time, is the birthday attack. In this section, the original example of the birthday attacks and the practical problems of the hash functions will be explained with calculations.

2.3.1 Original Example

The original question of the birthday attack is that there are 23 people in the room, and people want to know the possibility of an existing birthday

match. The possibility can be calculated using the probability theory if there are r people in the room ($r \leq 365$) [1]:

$$P(\text{birthdaymatch}) = 1 - \prod_{i=1}^r \left(1 - \frac{i-1}{365}\right)$$

And it is obvious that if $n = 23$, the probability is greater than 0.5.

2.3.2 The Weakness of the Hash Function

The birthday match above can be treated as the collisions in hash functions. Because the input of the hash function is arbitrary and the output length is fixed, collisions must happen if we select a sufficient number of input strings. Here, we will do an estimation of the number of strings we select to have a significant probability of collisions. Assume that all the outputs y in the hash functions have the same probability of occurring. Then, the probability of having collisions if we choose r different inputs and the total number of possible outputs is N can be calculated [1]:

$$p(\text{valuematch}) = 1 - \prod_{i=1}^r \left(1 - \frac{i-1}{N}\right) > \epsilon$$

The approximate value r when $\epsilon=0.5$ is $1.1774\sqrt{N}$. Hence, we are likely to find a pair of messages with the same hash value after calculating $\lceil 1.1774\sqrt{N} \rceil$ different messages. So the attack on the collisions of the hash functions is often choosing \sqrt{N} inputs and finding collisions in the outputs. Thus, if we increase the length of the hash function outputs, we can significantly increase the difficulty of finding collisions. In SHA-1, 2^{80} inputs are needed to find collisions while one can attack the MD5 with only 2^{64} inputs [2]. Due to the current computing power, we often use the SHA-256, which has 256-bits output to maintain the third rule of hash functions.

3. Digital Signature

A digital signature is an electronic version of a hand-written signature in transactions. The purpose of a digital signature is to verify that the person agrees with the contracts and terms. Usually, hash functions are used in the digital signature scheme to prevent the existential forgery attacks. There are some efficient digital signature algorithms introduced in the following sections, such as RSA, Elgamal and DSA.

3.1 How a Digital Signature Works

A digital signature is based on asymmetric secret schemes. Alice publishes the public key e and keeps the private key d in secret. The encryption function using the private key d is denoted by

$$c = \text{sig}(m, d)$$

and the verification function using public key is denoted by

$$v = \text{check}(c, e)$$

If Alice wants to sign a document, she need only send the information pair $(m, \text{sig}(m, d))$ to the other parties. The other parties can verify the information by using the public key e and see if

$$\text{check}(\text{sig}(m, d), e) = m$$

Take the most famous RSA scheme; for example, if Alice's public key is $(n = pq, e)$, her private key is d and p, q are two large prime numbers only known by Alice. If she wants to sign the message m . She can compute $c \equiv m^d \pmod{n}$ and send c to Bob. Bob can verify the message by checking whether $c^e \equiv m \pmod{n}$.

In the following sections, two similar digital signature schemes will be analyzed.

3.2 The Example in Elgamal

The RSA signature that is presented above uses the computational difficulty of the "factorization of large number" to make sure that it is hard to find the private key (p, q, d) . The Elgamal signature uses another computational non-polynomial problem called "the discrete logarithm problem" to maintain the security in communications. Because there is no easy algorithm to find the solution x to the discrete logarithm problem

$$a^x \equiv b \pmod{p}$$

where p is a large prime, even the fastest algorithm we now have cannot solve the discrete logarithm problem in polynomial time. However, as we can see in the process of the Elgamal signature scheme, it is easy for every user to set up the keys (the public key and the private key) and verify every message he/she receives with the private key.

For Alice, who wants to sign the message or document m , she needs the following steps [2]:

1. Set a large prime p and a primitive root α of p ($0 < \alpha < p$). Choose a private key a ($0 < a < p$) and set $\beta \equiv \alpha^a \pmod{p}$.
2. Choose a random number $0 < k < p-1$. Set $r \equiv \alpha^k \pmod{p}$ and $s \equiv k^{-1}(m - ar) \pmod{p-1}$. Then publish (p, m, r, s) .

For Bob, who wants to verify the message sent by Alice, he needs to download Alice's public keys and do the following calculations:

1. Compute $v \equiv \beta^r r^s \pmod{p}$ and $u \equiv \alpha^m \pmod{p}$.
2. Check if $v \equiv u \pmod{p}$, because if Alice sends the message signed by her private key, $v \equiv \beta^r r^s \equiv \alpha^{ar} \alpha^{ks} \equiv \alpha^{ar+ms-ar} \equiv \alpha^m \equiv u \pmod{p}$ [2].

From the process above, the Elgamal signature scheme uses the power of prime congruence functions and performs some algebraic transformation to the power. Currently, we use the DSA algorithm that evolved from the Elgamal signature. However, the main difference between the two algorithms is that the DSA requires two prime numbers $p, q, q | p-1$. This special feature makes the DSA more secure because the attacker also needs to put in additional effort and computational power to deal with q .

3.3 The Application of Hash Functions in Digital Signatures

Usually, we sign the hash value of the message $h(m)$ instead of the original message m . The purpose of using hash functions in digital signatures is basically to reduce the calculation time. The message length can be reduced by the hash function, thereby reducing the calculation time in the digital signature and maintaining the security of information transformation. For example, in RSA, we need to calculate the ciphertext $c \equiv m^d \pmod{n}$. In this case, m may be exceptionally long according to the original message length, so directly computing the " m^d " takes up time and space. The hash function can reduce the time and space by changing it into a 512-bit hash value. [1]

4. The Theory of Blockchain

Blockchain is a cryptosystem that enables people to transfer digital assets in a distributed consensus. The transaction information in the consensus networks is operated with hash functions and digital signature schemes. In the blockchain, there are three important components: information security,

consensus protocol, and the communication network. Firstly, we need to make sure which user or address sends the message to the network to ensure the validity of transaction. Secondly, the users in the consensus are not controlled by centralized authorities, so they need to make an agreement on the execution of the system. The security of the system also means that the blockchain system is protected from the adversaries who want to attack it. In the following sections, the three important components of the blockchain will be explained mathematically [9].

4.1 Point-to-Point Transaction

Every account in the blockchain system is assigned to one specific address. This address is not related to a user's identity because of the anonymity of the system. The address can be used by anyone who holds the private key corresponding to the address. This concept is similar to a bank credit card and the password of the credit card. If you have the password for a specific wallet, you own the account and the money in it. By statistics estimation, each user in the blockchain network has more than one addresses, and each address has a different pair of private and public keys.

The process of a blockchain transaction is the same as signing a document with a digital signature. A and B's addresses are denoted by A_{ad} and B_{ad} . The transaction time is t and the information sent is x . Then the information published to the whole network will be $T = A_{ad} || B_{ad} || t || x$, in which the symbol $||$ represents the combination of strings. We also need to verify that A is the person who sent the money to B. A needs to send both T and his private key signature of T , denoted by $Sign(T)$, to the public network to clarify himself as the payer. Then B receives the digital signature from A, and B can verify the transaction document by using A's public key. In a decentralized network, the transaction is "broadcasted" so that all users can see A's transaction document and verify whether the document and signature match.

4.2 The Communication Network: The Byzantine Problem

In an anonymous network, the adversaries are common and attacks on the blockchain network are frequent. The powerful adversaries may control some of the nodes in the network that are called the "corrupted nodes." Additionally, the network may also cause information delay or mistakes. These problems are modelled and studied as the "Byzantine problem". The goal of studying the "Byzantine problem" is to ensure the security of the consensus and protect the consensus from the enemies and errors in the environment. There are many papers now to prove that the decision-making

in the blockchain will not be affected when the adversary proportion is less than a certain proportion of all users.

The original Byzantine problem is proposed by L. Lamport in 1982 [5]. The problem points directly to the security of the “point-to-point” information exchange system. The original problem is that there are n generals in the Byzantine, and they want to take a military action against their enemies. However, there are some traitors among the generals, and they send the wrong message to confuse others. The solution is to find a “Byzantine Agreement” that makes the right decision even with the presence of adversaries or “corrupted parties.”

Lamport stated in his paper that if the adversaries made up less than $\frac{1}{3}$ of the total users in the network, the decision-making could be processed as normal. The way to prevent disturbances in decision-making was that the nodes communicated with each other about the message they received. After Lamport, many researchers tried to prove the “Byzantine problem” under different kinds of consensus protocol. When the Bitcoin consensus network was first proposed in 2008 [4], Satoshi Nakamoto stated that the Bitcoin blockchain incentivized good behaviors financially and most users would follow the right protocol.

However, his statement was not supported by mathematical proof. In 2015, the paper written by Garay et al. [9] proposed a proof that the bitcoin protocol satisfied the bound $\frac{1}{3}$ in the Byzantine problem if the length of block chain was sufficiently long, i.e. the probability that the current blockchain had errors dropped exponentially with the increase of the blockchain’s length. When studying the blockchain, the consensus protocol in the environment is the key to prevent attacks from adversaries, and researchers use the “Byzantine-Tolerant Problem” as a model to analyze the security of the system.

4.3 Different Kinds of Consensus Protocol

In the previous sections, the key point in the “Byzantine-Tolerant Problem” is to find an agreement in the consensus against adversaries and corrupted nodes. The information in the blockchain can be divided into two parts: the pending part and the confirmed part. The newly published transactions are the pending part waiting to be verified and added to the chain, while the confirmed part is composed of the previous blocks added to the chain. Since everyone can add a block to the end of the chain, the problem is to find an agreement to decide which block is a valid ledger of the current transactions. This agreement is called consensus protocol in the blockchain network. In the blockchain system, there are several kinds of consensus protocols.

4.3.1 Proof of Work (PoW)

The PoW protocol is a financially incentivized protocol because it encourages blockchain users to maintain the consensus with rewards. The core of the PoW protocol is the cryptographic hash function that can only be solved by brute force and the user who has higher computing power will be more likely to solve the problem and get the rewards from the system. The users who try to solve the problem with their computations are called “miners” and they will get a certain amount of money by successfully solving a problem [6].

This protocol solves the problem that the adversary may have more than one account in the network and exert influence on the decision-making in the consensus because the decision-making contribution of each party is proportional to its fixed computing power. After a miner announces that he has found the solution to the hash function, other miners will check the authenticity of the new block and add new blocks to the end of the current block if they think the information in the block is correct. Note that the longest chain will be regarded as the valid chain in the system. The problem of the PoW protocol is that it costs too much computing power in the network. Statistics also show that the cost of electricity and hardware to maintain the Bitcoin PoW system is more than \$1 million per day [10].

4.3.2 Proof of Stake (PoS)

The PoS protocol is based on the users’ economic stakes in the network. Unlike PoW that is based on computing powers, the users in the PoS protocol vote for decisions based on their deposits. When deciding whether a record should be added to the transaction ledger, every voter in the network sends a deposit to the network and the user will get the chance to add the block according to the deposit paid to the network. Once a user gets the chance to add the block, he can then add the block to the end of every previous block and the system will accept the longest chain to be valid [10].

4.3.3 Practical Byzantine Fault Tolerance (PBFT)

The basic thoughts of the PBFT algorithm originated from the “Byzantine General Problems.” If there are f corrupted nodes in the network, we need a $n \geq 3f + 1$ group of people to make the right decision. In the PBFT protocol, there is a node that sends the transaction or information to the “primary node” in the network. The primary node is chosen by the PBFT and the primary node should not be corrupted. After the primary node receives the request from the message-sending node, it will then send this message to all the others in the decision-making group. Then the other nodes will verify the information and send their operation result to the node, which requests

the decision. The primary node will make a final decision when it receives $f+1$ same decision results from the other nodes in the decision-making group [11].

5. Blockchain Applications

In this part, two representative examples of blockchain will be introduced: Bitcoin and smart contracts. Bitcoin is the first cryptocurrency created using blockchain. Since bitcoin, many other cryptocurrencies have been introduced to the market and the economic values of cryptocurrencies have become a widely discussed topic. Another direction of blockchain development is smart contract, codes that can be operated in blockchain networks. Smart contracts are rules written in blockchain networks for everyone to follow. People can use codes to implement their smart contracts on the Ethereum network. The final part of section 5 will be my own implementation of smart contract and some analyses of the future of blockchain.

5.1 Bitcoin

Bitcoin was created by Satoshi Nakamoto in 2008. The purpose of the Bitcoin is to create a transaction system where money can be sent directly from one party to another without authorities. The system is maintained by a distributing consensus and the security of transactions is protected by cryptographic applications [4]. Blocks will record all the transactions in the given time. The information recorded will be the electronic address of the dealers, the time of transactions, and other values that are important to prove the authentication and order of the transaction.

The bases of blockchain technology are hash functions and the signature scheme. The hash functions are denoted by $G()$ and $H()$ which are two SHA-256 hash functions and both functions $G()$ and $H()$ have 256-bit outputs. Meanwhile, the signature function is denoted by $s = \text{Sign}(T, d)$, which is a DSA algorithm using the private key d of the payer, and the corresponding function to verify the identity of the money owner is denoted by the $v = \text{Ver}(s, e)$ with the public key e of the payer. [12]

5.1.1 The Transaction

The transaction procedure is the same as the process illustrated in section 4.1. The money payer A will broadcast the transaction information T and the signature created by A 's private key $s = \text{Sign}(H(T), d)$ to all the nodes in the network and every user can verify A 's signature with the $\text{Ver}(s, e)$ function. However, transferring bitcoins is a bit more complex than simple

information exchanges in a point-to-point network. Every transaction has an output called “the unspent transaction output” (UTXO). For example, if A has 25 BTC in one of his addresses and he wants to send 15 BTC to B, then the UTXO in the transaction is 10 BTC. So, the system will change the address of 15 BTC to B and then send the 10 BTC back to A’s address. Figure 1 shows some examples of transactions. Each transaction is compressed into a string that represents its unique identity, and the money in one account is separated into two parts: the first part is sent to recipient, and the other part is sent back to a new address which belongs to the sender.

5.1.2 Create the Block

The money will not be immediately transferred to B until the transaction information is added to the public ledger. After the users verify the transaction between A and B, the next step is to record the transaction in the ledger. Note that the transaction record should only be added to the blockchain by one user and it should be agreed by other nodes that this record is valid. After verifying the transaction information, users then need to put the record in the public ledger. In the blockchain system, the transactions are recorded every ten minutes. The new transactions during these ten minutes are combined with the hash value of the previous blocks to form a new block. By adding the hash value to the previous blocks, users can make sure that all the blocks are recorded chronologically, and they can verify the time order from the first block to the current one.

Therefore, in each block, three parts of the information are crucial: the previous block hash value s , all the transaction information T during the new 10-minute period, and a chosen value ctr called the “nonce value.” Consequently, each block will be denoted by a vector

$$B = [s, T, ctr]$$

The transaction information is

$$T = T_1 || T_2 || T_3 || \dots || T_n,$$

in which each $T_i, i = 1, 2, 3, \dots, n$, is a single broadcast transaction. The hash value of each block $B = [s, T, ctr]$ can be calculated by

$$H(ctr, G(s, T)) \text{ [9].}$$

Given the fact that the previous hash value and the transactions are available to all users in the networks, we need to choose one block generated

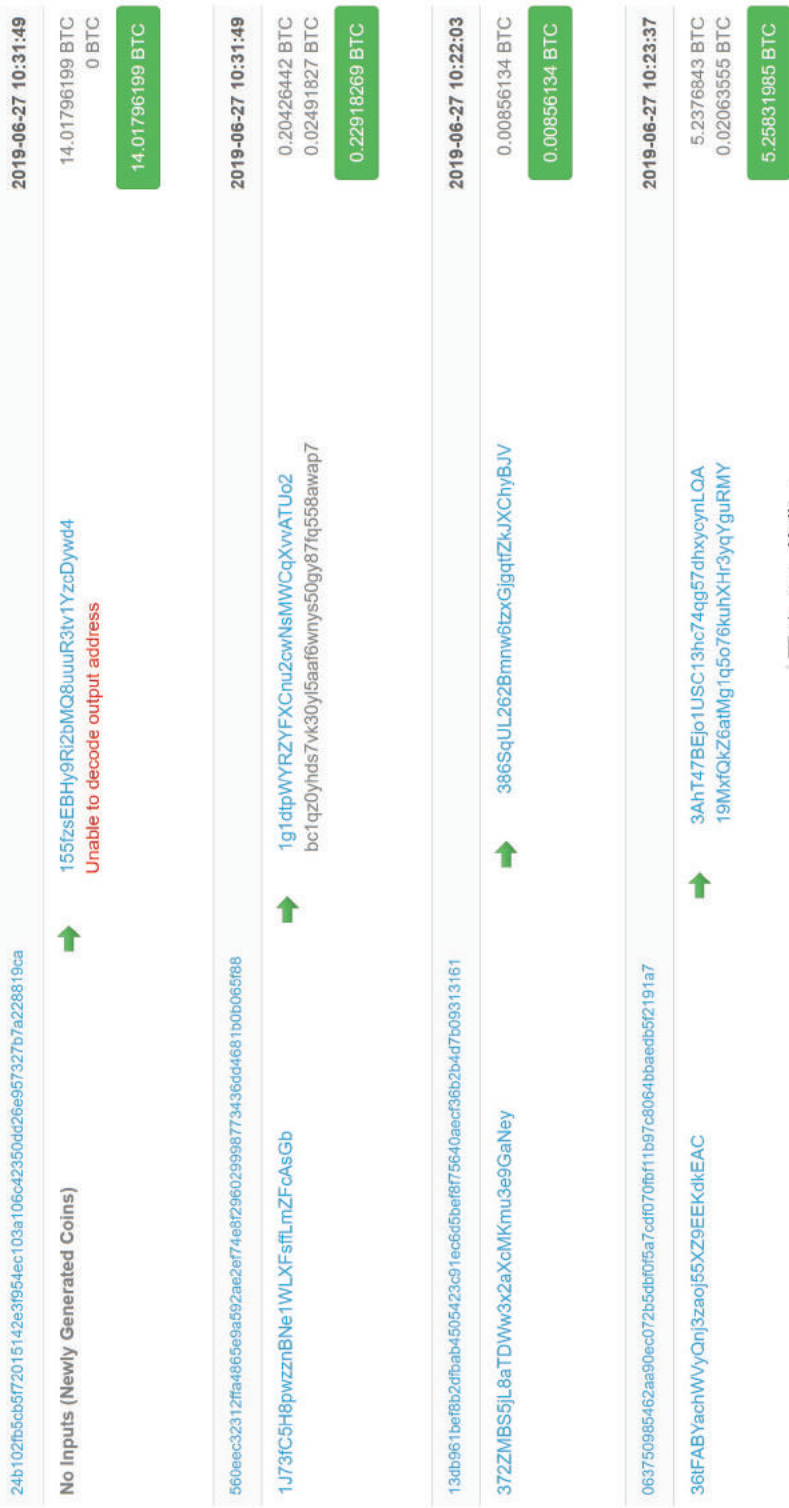


Figure 1. Examples of Transactions [7]

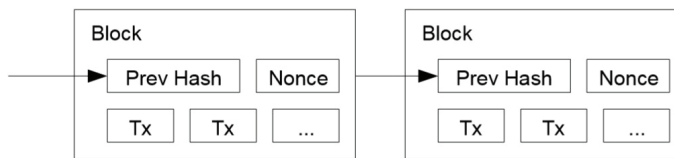


Figure 2.
Building the Block [4]

by the users. The random selected “nonce value” is the key to fulfill this requirement. In the following sections, some methods and protocols will be introduced to solve the problem. Figure 2 explains how blocks link with each other chronologically.

5.1.3 Consensus Protocol in Blockchain: Proof-of-Work

Deciding which user should record the transaction is important and the proposed solution to the problem is a computing race called the “Proof-of-Work”. The blockchain system is maintained by several users called the “miners.” These miners get paid for their contribution to make the system valid and secure. They earn money by creating the blocks and adding them to the blockchain. When they are trying to create the block, they need to solve a difficult and time-consuming problem: the hash function of the block. As mentioned in section 2, the hash function is a one-way function, so it is difficult to find the solution m of the function $h(m) = y$ with a given y value. The miners can only solve the problem by enumerating each possible solution, so the possibility that two miners find the solution at roughly the same time is incredibly low.

The computing race is set to a certain difficulty z to make sure that the block can be generated in about 10 minutes. The requirement of a valid block $B[s, T, ctr]$ in this condition satisfies that

$$H(ctr, G(s, T)) < z.$$

In binary form, this requirement is equal to the hash value of the block containing at least y consecutive 0 at the beginning of the hash value. Currently, this y value is set to 69 in order that there is one block added to the chain every 10 minutes. The first miner to find a hash value less than z with a certain the correct nonce value ctr will then tell the other miners the result and the others will verify the hash value with the nonce value ctr chosen [4,9]. Figure 3 shows all the information contained in each block.

Summary	
Number Of Transactions	2727
Output Total	20,914.91190395 BTC
Estimated Transaction Volume	1,102.43876112 BTC
Transaction Fees	1.51796199 BTC
Height	582667 (Main Chain)
Timestamp	2019-06-27 10:31:49
Received Time	2019-06-27 10:31:49
Relayed By	BitClub Network
Difficulty	7,934,713,219,630.61
Bits	388200748
Size	1259.71 kB
Weight	3992.797 kWU
Version	0x3FFFE000
Nonce	336277466
Block Reward	12.5 BTC
Hashes	
Hash	00000000000000000008cb7724f1297e0e1652daed7ed868d656b120c07c93491
Previous Block	0000000000000000000000152966667c6bccaa5bbb5d306276292457c6377145114b
Next Block(s)	
Merkle Root	c2536bd38a3a470541e5366cf620357e60ec9af415fd88914088444daaa928a9

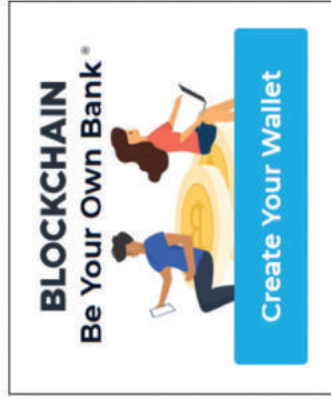


Figure 3.
All Information in the Block [7]

5.1.4 Balance Check and the Longest-Chain Rule

Since the cryptocurrencies in the blockchain are not controlled by centralized authorities and exist in a virtual world, there are more transaction problems for cryptocurrencies than usual paper money. Someone may spend more money than is in their account or create fake transaction blocks in the network. We need some methods and rules to protect the blockchain network.

To prevent users from spending more money than is in their account balance, we can check the balance in the user's account by tracing back the previous blocks in the blockchain. So if the miner finds that the balance in the sender's account is less than the money spent, he will reject it, recording the transaction in his ledger.

Another problem is "double spending [4]." For example, user A has 10 BTC in his account, but he sends 10 BTC to both B and C at approximately the same time. The information broadcasted in the network may be delayed, so it is hard to determine who gets the money from A's account. The miners may have disagreements. But the proof-of-work method will determine the final decision because there is going to be a miner who gets the answer of the hash function.

Even if the two miners with the different ledgers calculate the answer at the same time, there is another method to ensure that only one history of transaction is recorded and confirmed: the longest-chain rule. Since disagreements may occur, the blockchain is a tree structure with some small branches. To deal with branches, the blockchain system accepts the longest chain to be the history of transactions regardless of other shorter branches. If the two miners get the answers at the same time, the people who agree with the first miner will continue to create the block based on the first miner's block, and the second miner will have other supporters. But the probability of calculating the answer at the same time is almost impossible. So there is sure to be a longer chain and the shorter chain will be denied by all the users in the system. That is the solution to the problem of double-spending.

What if someone wants to add some changes to the transaction history to retrieve the money they spent? Because if he successfully builds another blockchain accepted by others, he can erase his money spending records and get his money back. But he needs to calculate the whole history of the blockchain after the changed block all by himself, and he also needs to create a longer chain than the true history. He is competing with everyone else in the network and it is impossible unless he manages more than 50% of the computers to calculate the hash function problems much faster than the others. But if his computing capability is stronger than the rest of the world, he will earn more from the award of creating the true history of the blockchain. So it is a waste to erase the history of the blockchain.

5.2 Smart Contract

While Bitcoin is the first implementation of blockchain technology, the consensus built by Satoshi Nakamoto has many problems to be solved and many other applications of blockchain have emerged. One of the main developments of the blockchain is the smart contract, and Ethereum is one of the most famous implementation platforms of the smart contract [8]. The purpose of Ethereum is to create an alternative protocol for building decentralized applications that is adaptable to many different interactive situations. Ethereum creates a large class of decentralized applications by building the ultimate abstract foundational layer of the blockchain network: a blockchain with “a built-in Turing-complete programming language, allowing anyone to write smart contracts and decentralized applications where they can create their own arbitrary rules for ownership, transaction formats and state transition functions [8].”

5.2.1 Accounts

There are two different types of accounts in the Ethereum system: externally owned accounts that create transactions, and contract accounts that act as agents dealing with transactions [8]. The contract agents have specially designed codes and run the codes when they receive messages from other user accounts in the system. These agents can also send messages to other contract accounts or external accounts. This feature enables multi-stage smart contracts, a huge development towards different kinds of blockchain applications.

5.2.2 Information

Information in the Ethereum can also be classified into two parts: transactions and messages. Unlike transactions, messages can only be produced by a contract account and sent to other contract accounts. The components in the information are similar to the point-to-point transaction, but the transactions and messages all contain an optional data field that may include additional information and executable codes for contract users and external users [8]. This feature also demonstrates the flexibility of the Ethereum network to implement different contracts.

Another difference compared to the Bitcoin blockchain is the transaction fee [8]. The transaction fee is determined by the steps of executing the whole process and the fee per step is denoted by “GAS”. Each user who sends a transaction or message needs to publish a variable denoted by “STARTGAS” that represents the maximum number of execution steps and the system will charge the fee “GAS*STARTGAS” to the sender and transfer to the recipient.

The recipient can then use the money received to help the sender do further executions. Finally, the remaining charge will be transferred back to the sender's account.

5.2.3 Mining

The PoW protocol is also used to add blocks to the Ethereum blockchain. Additional information recorded in the block is the current state of every node, while the Bitcoin blockchain only needs the transaction information without the balance in every account. Although this seems inefficient, the Merkle Tree structure used to store the state of every account turns out to be quite convenient [8].

5.3 Blockchain Implementation

The problem I want to solve with blockchain technology is an assessment system for high school students. The purpose of this assessment system is to record the community service and other activities in every student's personal CV for college application. However, this system is a centralized system that is controlled by schools and educational authorities. Teachers in schools must check every student's activities and assess the quality of these activities. They always complain that this task is annoying and time-consuming. Therefore, with the Ethereum platform, students can monitor each other and give votes to the activities which are valid for scoring, i.e. they give votes to activities that can be added to the blockchain. Students can post their activities to the network, and their activities can be recorded in the public ledger if they receive more than 200 votes from other students.

I use Remix-IDE to build and test my smart contract. First, the system needs to create students' accounts and assign these accounts to different addresses. Students can declare their new accounts by using the function `add_stu()`, and their information can be examined by using the function `find_info()`. The `add_score()` function can only be applied to the contract accounts but not student accounts. Figure 4-1 and 4-2 show the initializations above.

After creating student accounts, the students should be able to publish their activities to others in a public network. The events posted online will be recorded in a local array and made available to all the student users. Figure 5 shows the functions to define activities and add activities to a student's account.

To vote for a posted activity, students need to create a `VOTE()` event using the `vote()` function and their voting records will also be stored in the local storage. In the `vote()` function, the program should check if an address

```

1 pragma solidity >=0.4.0 <0.6.0;
2 contract SchoolContract{
3     struct Student{
4         uint id; //student number
5         string name; //student name
6         uint score; //reward scores
7     }
8     mapping(address => Student) studentaccounts; //student address
9     event Add1(
10        address _from,
11        uint id,
12        string name
13    );
14    function addstu(uint _id,string memory _name) public {
15        //add new student in a specific address
16        studentaccounts[msg.sender].id=_id;
17        studentaccounts[msg.sender].name=_name;
18        emit Add1(msg.sender, _id, _name);
19    }
20    function find_info(address _address) view public returns(uint, string memory,
21        uint){
22        //view specific student information
23        return (studentaccounts[_address].id, studentaccounts[_address].name,
24            studentaccounts[_address].score);
25    }
26 }

```

Figure 4-1. Initializations

```

function add_score(address _address) internal{
    //add score
    studentaccounts[_address].score++;
}

```

Figure 4-2. Initializations

```

29 struct Activity{
30     //activity information
31     uint num; //activity number
32     string detail; //detail description
33     address owner; //poster address
34     uint vote; //vote count
35     bool confirmed; //whether the event is approved to be scored
36 }
37 Activity [] events; //event storage array
38 uint nextNum=0;
39 event Add2(
40     uint num,
41     address _owner,
42     string _detail
43 );

```

Figure 5.
Activities Definition

has voted for one event more than once and if a user votes for his own events. If an event gets more than 200 votes, the contract accounts will act like administrators and give credits to the event's publisher. The smart contract I created for student assessment is demonstrated below in figure 6.

However, this program has only been tested on Remix-IDE but not the real Ethereum platform. To test in the real environments, I need to build a decentralized application which includes this smart contract. My own smart contract may not run as smoothly as other official smart contracts on the

```

77 struct Vote{
79     //post event info
80     address _voter;
81     uint _num;
82 }
83 Vote[] voteEvent;
84 event VOTE(
85     address _from,
86     uint _num
87 );
88 function vote(address _address, uint _num) public{
89     //vote event
90     bool check=true; //check repetitive voting
91     require(
92         //check self-voting
93         _address==events.owner,
94         "You can't give vote to yourself!"
95     );
96     for(uint i=0;i<voteEvent.length;i++){
97         if(voteEvent[i].voter==_address && _num==voteEvent[i].num){
98             check=false;
99         }
100     }
101     require(
102         check==true,
103         "Already voted!"
104     );
105     if(check==true){
106         voteEvent.push(Vote(_address, _num));
107         events[_num].vote++;
108         emit VOTE(_address, _num);
109     }
110 }
111
112 function cal() public{
113     //count votes and add scores
114     for(uint i=0;i<events.length;i++){
115         if(events[i].vote>200 && events[i].confirmed==false){
116             //the event should get more than 100 votes and is not confirmed
117             before
118             add_score(events[i].owner);
119             events[i].confirmed=true;
120         }
121     }
122 }
123 }

```

Figure 6.
Voting

Ethereum platform, and it may be vulnerable to cyber-attacks. Therefore, the method in this smart contract needs to be adjusted to build a better consensus. Additionally, since users need to pay transaction fees for every step of calculation in smart contracts, the number of steps in this smart contract should be optimized.

5.4 The Future of Blockchain

Long before Bitcoin was introduced by Satoshi Nakamoto, scientists had already conducted many studies on related topics, such as point-to-point

transactions, smart contracts, time-stamping, and decentralized networks. In fact, Bitcoin is a product built on top of all the previous studies related to blockchain technology. Since the introduction of the Bitcoin, more products have been invented and blockchain has become popular around the world.

However, developing blockchain technology is still challenging. At the core of blockchain studies is mathematics. The developments of hash functions and digital signature schemes provide the foundations for more secure and efficient information exchanges, and the properties of different consensus can be evaluated by mathematical proofs and probability computations [9]. In spite of these advancements, many problems still exist in the blockchain networks. For example, fragile key managements may be subject to cyber-attacks and properties will be stolen by hackers. Therefore, researchers have tried lots of key managements methods and tested their security. Beside security and privacy problems, researchers have not got a comprehensive understanding of the consensus that they create in blockchain networks. Many assumptions are only supported by behavioral economics but not mathematical proofs, and there is still a long way to go towards building “a stable blockchain.” [12]

Regardless of our inadequate understanding of blockchain, there are a lot of potential applications of blockchain, such as “proof of existence”, “decentralized storage”, and “Internet of Things” (IoT) [6]. Different features of the blockchain indicate its wide range of applications: it is a public ledger that helps people store information; its cryptographic foundations improve communication security and identity authentication; and it represents a new way of building trust in an anonymous group. In the future, blockchain will revolutionize our concepts of identities and interpersonal connections.

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