Thesis Proposal and Schedule of Thesis Writing
研究生选题报告及论文工作计划

Title: Determining the Tangible Conclusions that Can Be Drawn from COVID-19 Case Data for Strategic Supply Chain Decisions

题目: 确定可以从新冠肺炎案例数据得出的战略供应链决策的有形结论

学号: 2019280016

姓名: Theodore Alexander Endresen 安多

专业: 管理科学与工程

导师: 谢小磊

学院: 工业工程系

2020 年 10 月 15 日

Contents

1 Topic Selection and Significance

In this section, the research topic will be presented. Then, a background of the topic will be presented to provide further context. Finally, the significance of the research topic will be discussed.

1.1 Topic

The research topic is determining the tangible conclusions that can be drawn from COVID-19 case data for future strategic supply chain decision making. By deriving metrics from the COVID-19 case, death, and testing data on a per country basis, a snapshot of the effectiveness of a country's COVID-19 response can be created. Then, by leveraging these metrics against prior pandemic preparedness metrics, their accuracy can be measured in their aggregate and dimensional form, which could determine their validity to be used in strategic supply chain decision making in the future. Furthermore, by leveraging the COVID-19 metrics against other globally aggregated metrics, it can be determined if other confounding variables may better capture a countries COVID-19 data. This would seek to show the validity of the using the COVID-19 case, death, and testing data for such analyses or if pandemic preparedness can be considered in other areas of existing strategic supply chain decision making. Additionally, by considering the severity of the steps countries took to combat COVID-19 against their case, death, and testing data, we can draw further conclusions about the relative severity of a pandemic outbreak required for different countries to take measures that could affect supply chains, which would be a crucial factor in strategic supply chain decision making.

In short, after conducting this research the following two questions should be answered:

1. Is it reasonable to use the COVID-19 case, death, and testing data to help make strategic supply chain decisions?
2. If so, what does the data tell us in regard to a country's pandemic preparedness (e.g. what countries should one avoid when making strategic supply chain decision and vice versa)?

1.2 Background

In this section, COVID-19's effects on global supply chains will be explored. Then, a look at its overall economic impact will be discussed. Finally, the typical risks considered in strategic supply chain decision making will be mentioned.

1.2.1 Supply Chain Impacts

The COVID-19 pandemic drastically affected both global and regional supply chains. At this point in time, the worldwide shortages of toilet paper, face masks, hand sanitizer, and ventilators are common knowledge. However, beyond the shortages of a few products that were widely reported upon in the news, it is important to consider the severity of impacts COVID-19 had on supply chains overall. On April 14, 2020, the *Institute for Supply Management* (ISM) released its second wave of research on COVID-19's impacts on businesses and their supply chains" [1]. Some of largest takeaways from the report are listed below:

- "Almost one-half (47%) of respondents' report reduced revenue targets of 22% on average" [1].

- “The majority (57%) [of respondents] reported that demand for their products has decreased, on average, 5%” [1].
- “95% of organizations will be or have already been impacted by coronavirus supply chain disruptions” [1].
- “Average lead times for inputs are at least twice as long as compared to ”normal” operations, for Asian (222% for China, 217% for Korea, and 209% for Japan), European (201%) and domestically sourced inputs (200%)” [1].
- “[US] manufacturing is operating at 79% of normal capacity. Chinese and European manufacturing is at about one-half normal capacity, 53% and 50% respectively” [1].

From this data, the full scale of COVID-19's effect on global supply chains can be appreciated. However, it is not just the severity of COVID-19's impact that makes it important. In many ways, the supply chain disruptions COVID-19 has caused are far different from previous situations. Michael Wilson outlined four reasons why COVID-19 was unique in terms of the supply chain disruptions it caused: geographic scope, industrial scope, demand shame, and duration [2].

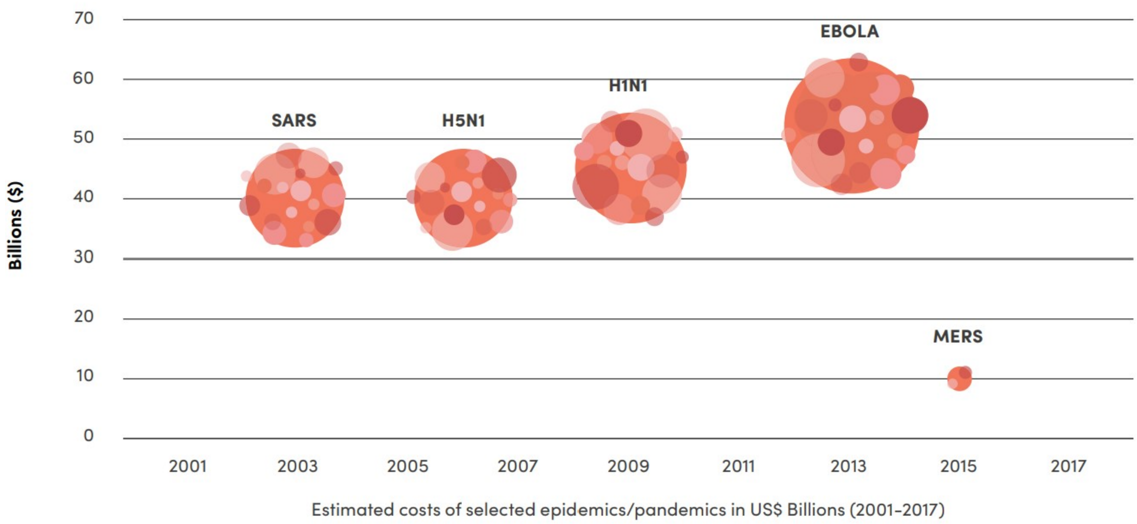
- Geographic Scope: the supply chain disruptions COVID-19 caused were global rather than regional. For example, “when food, water and medical supplies were in short supply due to Hurricane Katrina, they could be flown in from Houston and other cities. With COVID-19, on the other hand, those countries with necessary supplies have been reluctant to send them to other countries for fear they may need them at home” [2].
- Industrial Scope: COVID-19 effected almost every industry whereas other supply chain disruptions tend to effect specific industries.
- Demand Shame: in the past, it was believed supply disruptions would rarely affect the demand for high-end products. “As a result, [high-end producers] would continue producing lots of costly goods, expecting them to still sell briskly. But, COVID-19 is having an impact on high-end buyers, and many suppliers are now stuck with costly merchandise that is just not selling” [2].
- Duration: past supply disruptions tended to be measured in a few months (on the high end), but COVID-19 could affect supply chains for years to come.

Professor Sunil Chopra (the IBM Professor of Operations Management and Information Systems at Northwestern University) detailed another factor that has made the COVID-19 pandemic unique: labor disruptions. ”Weather-related supply disruptions have been much more common over the last 20-25 years, but this is the first time I have really seen a supply-disruption risk due to people not being able to go to work” [3]. Indeed, the COVID-19 shutdowns greatly exacerbated many supply chain related issues. They prevented workers from all but the most essential areas from going to work. Additionally, many of these shutdowns were nationwide as opposed to being regional in nature.

1.2.2 Overall Economic Impact

Since 2000, there have been pandemic outbreaks that have had measurable economic impacts. In September 2019, the *Global Preparedness Monitoring Board* outlined these specific pandemic outbreaks in their annual report on global preparedness for health emergencies. The outbreaks they analyzed were SARS, H5N1, H1N1, Ebola, and MERS. As shown in the figure below, the economic impact of these pandemic outbreaks was measured in the tens of billions.

Figure 1: Cost of selected epidemics (US$ billions) [4]



However, the report also noted that *The World Bank* estimated that a global influenza pandemic akin to the scale and virulence of the one in 1918 would cost the modern economy US$ 3 trillion, or up to 4.8% of gross domestic product (GDP); the cost would be 2.2% of GDP for even a moderately virulent influenza pandemic" [4]. However, in June 2020 the *World Bank's 2020 Global Economic Prospects Report's* "baseline forecast envisions a 5.2 percent contraction in global GDP in 2020" [5] due to the COVID-19 pandemic. Additionally, in the worst-case scenario "global growth could shrink by almost 8% in 2020" [5]. This would equate to a loss of $4.57 trillion, exceeding the *World Banks'* estimate for a worst-case flu.

For comparison, the most expensive natural disaster in recorded history was the 2011 Tōhoku earthquake and tsunami in Japan. "Japan' s government says the total cost of the damage caused by the tsunami could reach 25 trillion yen –or U.S. $309 billion" [6] which would equate to $353 million today. The most expensive man-made disaster was the 1986 Chernobyl Nuclear Disaster. The high-end estimate of the 30-year cost of the Chernobyl Nuclear Disaster is $700 billion [7]. Therefore, the economic impact of COVID-19 is expected to be nearly 13 times more expensive than the 2011 Tōhoku earthquake and tsunami and 6.5 times more expensive than the 1986 Chernobyl Nuclear Disaster.

1.2.3 Typical Strategic Supply Chain Decision Making Risks

On January 28, 2020, Mckinsey published an article on how to manage risk in the supply chain. They pointed to the importance of doing so with the increasing monetary cost associated with natural disasters as well as the trade disputes involving Brexit and the US-China Trade War [8]. Although they noted that many companies today try to implement multi-sourcing strategies when economically viable, they noted that ”many companies still follow a more-reactive approach in responding to supply-chain disruptions” [8]. Notably, Mckinsey recommended that all companies take four key steps in order to combat supply chain risk:

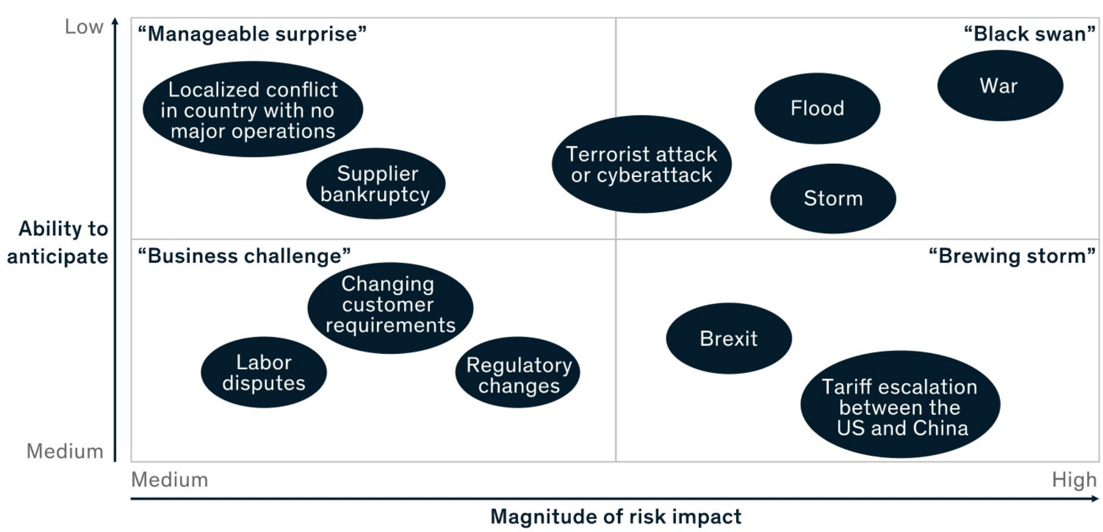
1. ”Identify the most relevant events and risks threatening to disrupt the company’ s supply-chain operations” [8]
2. ”Define possible outcome scenarios and assess their high-level impact” [8]
3. ”Develop response strategies for prioritized risks” [8].
4. ”Supply-chain risk management needs to be incorporated into regular decision-making and planning processes” [8]

Typical supply chain risks can be separated into four different categories:

1. “Manageable surprises” are difficult to anticipate but manageable in terms of impact [8]
2. “Black swans” are hard to anticipate and severe in terms of impact [8]
3. “Brewing storms” can be anticipated and will have a high impact once they materialize [8]
4. “Business challenges” are typically low-impact risks that can be both anticipated and managed quite easily [8]

These risks, their relationships, and where examples of specific supply chain risks are shown in the following figure.

Figure 2: A simple classification of supply chain risks [4]



It is important to note that pandemic outbreaks are not an example of a risk shown on the preceding figure or mentioned in the entire Mckinsey article, made all the more ironic considering it was released after the city of Wuhan was placed on lockdown due to COVID-19. However, this goes to show how pandemic outbreaks / pandemic preparedness has not been considered in strategic or operational supply chain decision making before. Due to their difficulty to anticipate and their high impact, pandemic outbreaks should be considered a black swan risk similar to floods, storms, and war.

Black swan risks are typically mitigated by "building strong crisis-management capabilities and resilience throughout the system" [8]. In particular, three main steps are typically taken to combat black swan risks:

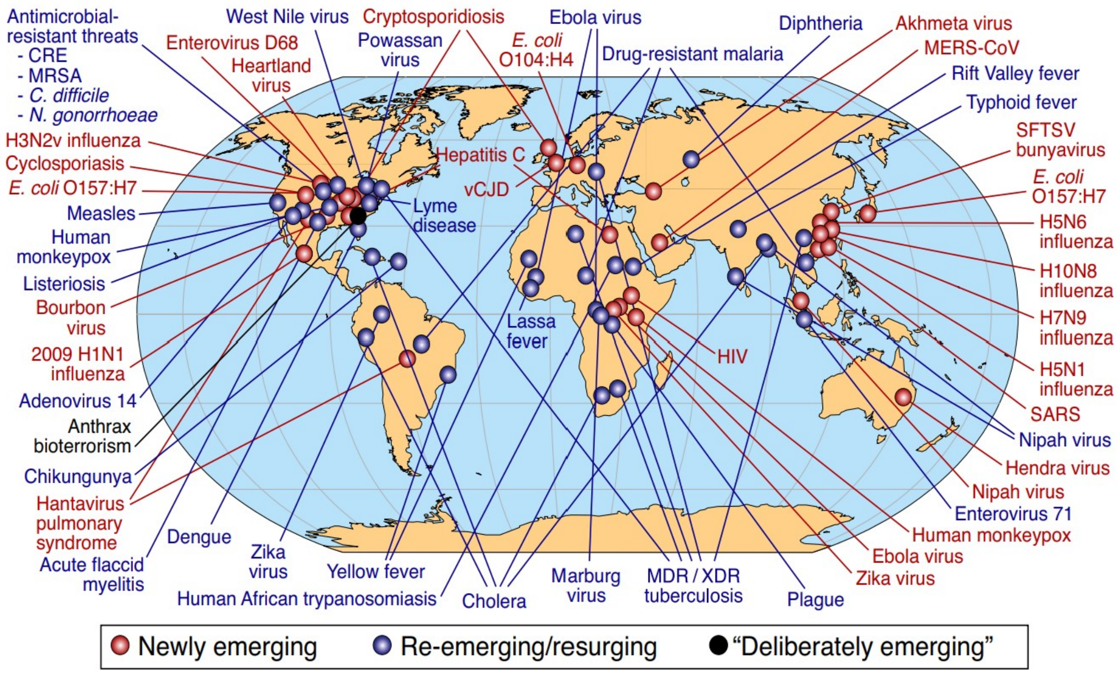
- "Introducing a systemic risk-monitoring process which can be enhanced by regular scenario-planning exercises" [8]
- "Keeping healthy reserves for parts with long recovery times" [8]
- "Transferring risk to other parties: taking out insurance and introducing risk-related contract language" [8]

1.3 Significance

It has been established that a major pandemic outbreak will have a drastic and severe negative impact on both global and regional supply chains. Furthermore, the economic impact of such a pandemic outbreak is many times worse than even the worst natural or man-made disasters. Finally, despite the severity of the supply chain and economic impacts of a pandemic, pandemic outbreaks and a country's pandemic preparedness have not been factored into traditional strategic supply chain decision making.

Furthermore, pandemic outbreaks are not a risk that is simply going to go away. "Between 2011 and 2018, WHO tracked 1483 epidemic events in 172 countries. Epidemic-prone diseases such as influenza, Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), Ebola, Zika, plague, Yellow Fever and others, are harbingers of a new era of high-impact, potentially fast-spreading outbreaks that are more frequently detected and increasingly difficult to manage" [4]. Below is a figure that further summarizes some of the outbreaks of pandemic potential disease over the past 50 years.

Figure 3: Global examples of emerging and re-emerging diseases [4]



This research topic is significant because it seeks to help quantitatively determine the validity of using the COVID-19 case, death, and testing data to aid in the strategic supply chain decision making process for the new black swan risk of pandemic outbreaks / a country's pandemic preparedness. Furthermore, as it will be discussed in the following literature review, there has been an ample amount of research about the different strategies companies can utilize to combat supply chain risks. However, this research has the potential to quantitatively provide the relative risk of locating parts of the supply chain in certain countries compared to others. Just knowing that the risk of a pandemic outbreaks can be alleviated by employing different risk management techniques (e.g. supply chain diversification) is pointless if all the locations in the supply chain are in countries that are ill-equipped to combat a pandemic outbreak.

2 Literature Review

In this section, research articles from both within and outside China will be analyzed. Then, comments will be made on the findings from the literature review. Finally, a private venture similar to this research will be discussed.

2.1 Within China

This section details the literature review conducted on papers within China.

2.1.1 How Do Firms Respond to COVID-19? First Evidence from Suzhou, China [9]

This paper used daily electricity data from 34,040 enterprises in Suzhou to observe the actual effects that the COVID-19 pandemic had on different industries. They examined the electricity data between December 31, 2019 and March 31, 2020 and compared it against a control group of identical data from the year prior. To make the analysis more targeted, the researchers categorized each enterprise into one of eighteen different types of firms. The enterprises were also labeled as to their relationship with the government and the business conditions they operated under. By performing a difference-in-difference analysis, the researchers were able to draw the following conclusions:

- Electricity consumption declined by an average of 57% overall
- The manufacturing industry was the worst affected (a further 37% more on average compared to other industries)
- Private firms suffered more than state-owned and foreign-owned firms
- Smaller firms were effected 30% more, on average, compared to larger firms

2.1.2 Response to the COVID-19 Epidemic: The Chinese Experience and Implications for Other Countries [10]

This paper identified many of the steps the Chinese government took in order to combat the COVID-19 pandemic in accordance with the *Regulations on Preparedness for the Response to Emergent Public Health Hazards* and outlined what this could mean for other countries. These actions that were taken are as follows:

- Quarantine Wuhan and eventually Hubei province
- Closed all public transportation in Wuhan
- Cancelled all Chinese New Year celebrations
- Closed all public places
- Constructed two emergency hospitals in Wuhan: Huoshenshan and Leishenshan

In addition to these measures, the paper also described other measures taken to help combat the economic and other effects of COVID-19. These actions are listed below:

- Reduced loan thresholds, increase loan amounts, and decreased interest rates
- Allowed business to apply for multiple tax relief and created government funds for hard-hit industries
- Implemented a ”gird closed management” system
- Utilized WeChat and AliPay to provide a system of health codes to control movement and mitigate risk

The main implications for other countries was that they had to be prepared to take drastic and emergency measures like China did in order to control the spread of COVID-19.

2.1.3 Lessons Learned from the COVID-19 Pandemic Exposing the Shortcomings of Current Supply Chain Operations: A Long-Term Prescriptive Offering [11]

This article outlines the effects COVID-19 had on global supply chains. It then details the shortages of essential goods and various supply chain issues. Finally, it gave recommendations on how to mitigate these effects and issues in the future.

The following impacts that COVID-19 had on businesses are shown below:

- Supply Shocks: as lockdowns swept the globe, a shortage of parts and raw materials plagued global supply chains
- Demand Shocks/Higher Variability in Demand: panic buying around the world resulted in demand shocks and demand variability
- Bullwhip Effect: "the shortcoming effect" (where downstream players falsely inflate their needs in anticipation of a scare resource) exasperated the bullwhip effect during COVID-19
- Transportation Requirements/Cost: global supply chains were undermined by closed borders and quarantine laws leaving air freight as one of the few options for international raw material and goods transportation

The following actions encompass what companies have already been doing, or are planning to do, to transform modern supply chains in response to COVID-19:

- Diversification/Dual Sourcing: many supply chains were disrupted due to their overreliance on China, therefore many countries are looking to diversify their supply chain in different geographical locations
- Vertical Integration of Supply Chains: vertical integration would help companies have better control over their value chain (a lack of which was exposed by COVID-19)
- Decentralizing Manufacturing Capacity: many companies are looking towards localizing supply chains
- Emphasizing Supply Chain Visibility: before the pandemic, only top-tier suppliers were considered, which left companies vulnerable to shocks due to disruptions with lower-tier suppliers
- Merging B2B and B2C/Flexibility in Supply Chains: by making a company's supply chain more flexible, a company is more able to respond to challenging demands
- Managing Shortfalls: in addition to allocating resources wisely to fulfill orders in accordance to a number of trade-offs, firms must predict the effects of COVID-19 on consumer needs

Based on these factors, the following three recommendations were recommended:

1. Nationalize Medical Supply Chains: this would allow better transparency and sharing of resources to comprehensively combat medical supply shortages during a pandemic
2. Adopt a "Plus One" Diversification Approach: overreliance on China lead to many shortages, although it will take a long time, making sure supply chains are diversified geographically outside China will be important
3. Increasing Safety Stock: the Just-in-Time model created many shortages during COVID-19; thus, extra safety stock may be needed in the future to combat shortages

2.1.4 Global supply-chain effects of COVID-19 control measures [12]

This paper created a model to test the effects of different control measures for COVID-19 on global supply chains. It operated in weekly increments and utilized an enhanced adaptive regional input to incorporate the sustainability of inputs and dynamic choices of supply chain linkages using the latest global trade modeling framework. This allowed the model to accurately model the bottlenecks in the global supply chain. The model primarily considered three factors in the control of pandemic spread: spatial spread (how many countries were affected), duration (the number of months lockdowns were imposed), and strictness (the percentage of labor and transportation capacity were reduced due to lockdowns). The main takeaways from the model were as follows:

- The economic cost related to initial COVID-19 lockdowns is largely dependent on the number of countries imposing lockdowns
- The economic losses are more sensitive to lockdown length than lockdown severity
- A longer lockdown that eradicates the disease can impart a smaller loss than a shorter lockdown
- Earlier and stricter lockdowns minimize overall loss
- A ”go-slow” approach (slowly lifting restrictions) may reduce overall damages if subsequent lockdowns are avoided

2.2 Outside China

This section details the literature review conducted on papers outside China.

2.2.1 Reducing the Risk of Supply Chain Disruptions [13]

This article described the importance of taking actions to protect supply chains from disruptions while considering the impact such actions would have on cost efficiency. It took note of the supply chain disruptions caused by the 2011 Japanese Tsunami, 2011 Thailand Floods, and the 2010 Eruption of a Volcano in Iceland. The authors noted that supply chains have become extremely optimized for cost, but that this has come at the cost of a lack of risk reduction.

The paper mentioned two methods to reduce the risk and improve the performance of supply chains:

1. Segment the Supply Chain: by having different parts of the supply chain in different geographical areas, the effects of disruptions can be minimized. Additionally, centralized production should be avoided.
2. Regionalize the Supply Chain: regionalizing supply chains would help reduce company loses by not allowing supply chain disruptions to extend beyond the regional level.

The paper mentioned two methods to reduce risk while limiting the impact on cost efficiency:

1. Reduce the Concentration of Resources: firms often choose to concentrate resources to reduce recurrent risks at the expense of disruption risk. The authors note that, in many case, two smaller manufacturing site can be nearly as cost effective as one large manufacturing site while mitigating disruptive risks.

2. Nudge Trade-Offs by Overestimating the Likelihood of a Disruption: humans often underestimate the chance of disruptive risk. By overestimating these risks in the planning phase, better results are usually achieved.

2.2.2 Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literature review [14]

This paper began by acknowledging the severe impacts that COVID-19 had on operations and supply chain management (OSCM). The ripple effects that came with the supply chain severe disruptions affected many industries and began in China. Most of the research about pandemics and OSCM revolved around resource allocation, distribution of medication, vaccine procurement, and emergency health response. However, the effects of pandemics on supply chains have not been rigorously researched yet. The findings of the literature review were as follows:

- The majority of papers (43.75%) were about influenza outbreaks
- Most of the papers presented optimization models for resource allocation
- Some papers pointed out the role of OSCM in influencing the duration of a pandemic outbreak by providing an adequate flow of materials

The researchers then formulated a list of possible research areas for OSCM under epidemic outbreaks and pandemics. They were as follows:

- Adaptation Focus: re-allocation of supply and demand, flexible production technologies
- Digital Focus: digital twins, data analytics and AI, digital manufacturing, block-chain
- Preparedness Focus: pre-allocation of resources, emergency distribution planning, product diversification and substitution
- Recovery Focus: forecasting pandemic propagation and ramp-up decisions, recovery of workforce and infrastructure
- Ripple Effect Focus: control of disruption propagation, modeling pandemic scenarios and structural dynamics
- Sustainability Focus: viability analysis, intertwined supply networks, consideration of supply chain ecosystems

2.2.3 Thinking ahead about the trade impact of COVID-19 [15]

This paper begins by making the distinction that the COVID-19 pandemic is different from previous, post-war pandemics because they typically affected less economically important nations. Thus, the COVID-19 pandemic has the potential to substantially slow world trade. Additionally, many of the most affected countries are some of the biggest manufacturing producers in the world. The paper noted that the manufacturing sector, as a whole, was hit the worst and that significant supply and demand shocks should be expected across industries.

The paper highlighted the fact that "supply-side contagion" was one of the biggest factors effecting international supply chains. Many of the worst hit or effected countries: China (the workshop of the world), Italy, USA, South Korea, and Japan are major supply chain hubs in the textile and information and communication technology (ICT) sectors. Furthermore, the ICT sector was particularly vulnerable due to their practice of keeping very lean inventory levels and supply chains. The automobile sector in East Asia was also severely impacted by part shortages for this same reason.

The paper concluded that COVID-19 had the potential to damage the trade systems global supply chains rely on. The USA's trade wars against its trading partners (especially China) coupled with COVID-19 may lead to a push to repatriate supply chains, which the authors think would be a mistake. Depending on suppliers from any one country is risky. Instead, the authors claim it would be more beneficial for firms to rely on dual-sourcing strategies at an additional cost as well as utilizing ICT for more effectively coordinate global sourcing.

2.2.4 Will the COVID-19 Pandemic Really Change the Governance of Global Value Chains? [16]

This paper began by acknowledging the severe impact COVID-19 has had on global value chains. However, they question how much global value chainswill actually change post-COVID-19 because they have succeeded due to their efficiency in the past; thus, why would new and less efficient global value chains arise post-COVID-19? They also noted that governments (including the European Union, United States, Japan, and India) are now focusing on repatriating supply chains.

Given that it is unlikely the guiding principles of global values chains will change (i.e. they will still be focused on cost and efficiency), the four following research areas are likely to arise from the COVID-19 pandemic in terms of multinational enterprises and global value chains:

1. Investment in Intelligence and Contracting Safeguards: how will multinational enterprise management teams adjust to better control bounded rationality and bounded reliability? Should firms look to "micro-modularize" value chains to allowed for easier substitution?

2. Levels of Irreversible Investments Abroad: the COVID-19 pandemic has shown public policy makers can shut down entire sectors of the economy without warning or negotiation. The question is if firms will be less inclined to invest highly specific assets abroad when they cannot be reliably ensured protection against future discriminatory government policies targeting foreign actors.

3. Relational Contracting with Key Partners and Ex Post Governance: with multinational enterprises being less able to protect business interests across global value chains, will they look to shift more micro-level contracting with critical partners?

4. Levels of Diversification: Will firms begin to engage in higher product and industry diversification?

2.2.5 Overreliance on China and dynamic balancing in the shift of global value chains in response to global pandemic COVID-19: an Australian and New Zealand perspective [17]

This paper pointed out there are two major viewpoints about how to handle the supply side of global value chains. The first is to promote further integration among members with a central supply from Asia. The second is ideological in nature and argues for the repatriation of supply chains. In the midst of the COVID-19 outbreak, Western policy makers are more focused on the ideological outlooks with Japan, the USA, and the EU introducing or discussing policies to incentivize repatriating value chains from China.

Before the pandemic, Australia and New Zealand held the view that they could prosper through developing their strategic position at both ends of the China-centered value chain (from natural resources and agriculture to education and tourism). However, the COVID-19 pandemic has put a stop the entire value chain. As Australian and New Zealand firms look to create resiliant supply chains, firms may begin to look for partners that are more ideologically aligned (e.g. USA, UK, and Western emerging markets like India and ASEAN).

The authors believed that cutting ties with China would be unwise. They believed the key to achieving resilience is through dynamic balancing. First, firms should try to build at least two interchangeable and complementary value chains that do not solely rely on China. Second, firms should rely in intermediaries with strong international connections around the globe. Finally, firms should look to incorporate their current guanxi networks in this new process and support each other throughout the pandemic.

2.3 Literature Review Takeaways

Below, takeaways have been summarized from the literature review:

- The COVID-19 pandemic severely disrupted global supply chains and was fundamentally different in nature from other supply chain disruption firms were equipped to handle.
- The nature of a country's lockdown is closely related with the economic impact COVID-19 had on the country.
- Many firms will look for ways to modernize their global supply chains to make them more resilient in the future.
- A lack of supply chain diversification was one of the main contributing factors for the supply chain issues that arose from COVID-19.
- Firms should begin to look for ways to diversify their supply chain geographically, industry-wise, and product-wise to better cope with future supply chain disruptions.
- Supply chains overly concentrated in specific countries or geographic regions were the most effected, especially the manufacturing sector.

One of the main themes throughout many of the articles was that an over-reliance on China as the world's factory significantly disrupted global supply chains. In fact, an over-reliance on any one country for any one part of the supply chain should be avoided in the future. While some policy makers are pushing for the repatriation of supply chains, that also creates an over-reliance on a specific country (the home country). In addition to geographic diversification, utilization of new technologies should be employed to mitigate the risk of supply chain disruptions.

The most important takeaway from this literature review for the research was the fact that, while many advocated for geographic diversification within supply chains, there were no discussion how to select these countries in a quantitative manner. While one paper suggested looking for partners in countries with similar ideological principals, no approach had considered utilizing the COVID-19 data to evaluate a country's pandemic preparedness in terms of strategic supply chain decision making. Thus, this research is significant because, to diversify global supply chains geographically to avoid the effects COVID-19 has had on supply chains, one must incorporate the COVID-19 data into this process. Otherwise, the strategic decisions firms make will not prepare them for the next pandemic outbreak.

2.4 An Instance Similar to My Research

One private company has begun work to solve this problem. *Verisk Maplecroft* is a global risk and strategic consulting firm based in the UK. It analyzes key political, economic, social, and environmental risk affecting global businesses and investors. They published an article on July 2, 2020 titled *Pandemic quickens diversification of supply chains beyond China.* In this article, they created a Recovery Capacity Index using a five-pillar framework to assess the ability of countries to bounce back after the COVID-19 pandemic. The nature of the five-pillars was not elaborated upon. They used this framework to analyze 12 countries: USA, Mexico, China, India, South Korea, Japan, Bangladesh, Vietnam, Indonesia, Thailand, Singapore, and Malaysia.

Although similar in its goal to this research. There are a few key differences:

1. This research is focused on every country, theirs focused on twelve countries.
2. This research is explicit in its framework, their methodology is not formally outlined.
3. Their focus was specifically on a country's ability to bounce back from the COVID-19 pandemic, this research's focus is on using the COVID-19 data to draw conclusions for future strategic supply chain decisions regardless of how a country will bounce back from the COVID-19 pandemic.
4. This research specifically focuses on the quantitative analysis of the COVID-19 case, death, and testing data. The extent to which their analysis used the COVID-19 case, death, and testing data in unclear.

Thus, although both goals are similar, to identify counties to best diversify supply chains, enough parity exists between their analysis and this proposal to make this research worthwhile pursuing.

3 Research Objective

Overall, the research can be broken down into the following objectives:

1. To sift through the available COVID-19 case, death, and testing data and develop a list of metrics that captures the observed effectiveness of a country's COVID-19 response that can be derived from this data.

2. Compare these metrics to *Johns Hopkin's 2019 Global Health Security Rankings* to determine their validity for being used for the consideration of the black swan risk of a pandemic outbreak for future strategic supply chain decision making.

3. Compare these metrics to other globally aggregated metrics (e.g. economic factors, healthcare quality factors, and press freedom) to identify confounding variables that either bias the COVID-19 case, death, and testing data or to determine if these globally aggregated metrics could be used as pandemic preparedness metrics.

4. Leverage the *University of Oxford's Stringency Index* to determine if the *Global Health Security Rankings* accurately predicted the degree of steps countries took to combat COVID-19

Additionally, time permitting and dependent on whether or not the COVID-19 case, death, and testing data is deemed reasonable to use for determining a country's pandemic preparedness, a new set of rankings could be constructed to evaluate a country's pandemic response based on the COVID-19 case, death, and testing metrics.

4 Methodology

In this section, the methodology proposed to conduct this research will be presented. First, the data sources that can be used to conduct the research will be detailed. Next, aspects of the data preprocessing that need to be undertaken will be discussed. Then, the different metrics that will be generated based on the collected data will be presented. Finally, the different analysis methods that will be used to draw conclusions from all the data and calculated metrics will be explained.

4.1 Data

In this section, the data soruces that can be used to conduct this research will be detailed.

4.1.1 Case and Death Data

The COVID-19 case and death data can be pulled from *Johns Hopkins Whiting School of Engineering's Center for Systems Science and Engineering's* Github page [18]. The case and death data are updated daily in two different .csv files. The format of both data sets is identical and presents a cumulative time series of the the number of COVID-19 cases/deaths stratified by country (and in some cases by province/state too). An example of the data sets is provided below:

Table 1: COVID Case/Death Data Example

Province/State	Country/Region	Lat	Long	1/22/2020	1/23/2020	...	9/27/2020
	Chile	-35.68	-71.543	0	0	...	457901
Anhui	China	31.83	117.23	1	9	...	991

4.1.2 Testing Data

The COVID-19 testing data can be pulled from *Our World in Data's* Github page [19]. The testing data contains testing data for 104 countries. However, unlike the case and death data, countries are not consistent with updating their testing data. Thus, the data is updated, by country, twice per week and entries are only added if countries have updated their testing numbers. Thus, each country's time series begins on different dates and it is not uncommon to see blank entries. An example of the data set is provided below:

Table 2: COVID Testing Data Example

Entity	Date	ISO code	Source	Daily Change	Cumulative Change	(Other Data)
Australia	9/23/2020	AUS	https://...	42410	7393693	...
Australia	9/24/2020	AUS	https://...	47634	7441327	...
Australia	9/25/2020	AUS	https://...			...

4.1.3 Pandemic Preparedness

Johns Hopkin's 2019 Global Health Security Rankings can be pulled directly from their website [20]. It ranks 195 countries' pandemic preparedness across six different dimensions as well as providing an overall score. In addition to the quantitative ranking, a categorical score is given to every country across each dimension and in the overall. The dimensions of the rankings are provided below.

- "**Prevention**: Prevention of the emergence or release of pathogens" [20]
- "**Detection and Reporting**: Early detection and reporting for epidemics of potential international concern" [20]
- "**Rapid Response**: Rapid response to and mitigation of the spread of an epidemic" [20]
- "**Health System**: Sufficient and robust health system to treat the sick and protect health workers" [20]
- "**Compliance with International Norms**: Commitments to improving national capacity, financing plans to address gaps, and adhering to global norms" [20]
- "**Risk Environment**: Overall risk environment and country vulnerability to biological threats" [20]

In addition to the quantitative and categorical scores, additional categorical data is provided in the form of region, population, and income. Below is an example of a compiled dataset. Some of the dimension columns have been removed due to space considerations.

Table 3: 2019 Global Health Security Rankings Example

Rank	Country	Overall (#)	Overall (Cat.)	...	Risk (#)	Risk (Cat.)	Region	Pop.	Income
135	Belize	31.8	Least	...	53	More	Latin Am.	<1m	Upper Mid.
150	Benin	28.8	Least	...	42.8	More	Africa	10-50m	Low
85	Bhutan	40.3	More	...	56.9	More	S. Asia	<1m	Low

4.1.4 Prevention Steps Stringency

The University of Oxford's COVID-19 Stringency Index can be pulled directly from their Github page [21]. "OxCGRT [the stringency intex] systematically collects information on several different common policy responses governments have taken, records these policies on a scale to reflect the extent of government action, and aggregates these scores into a suite of policy indices. OxCGRT collects publicly available information on 17 indicators of government response" [21]. The data is updated continuously. The data is presented as a time series where the Stringency Index changes over time. An example of the data is shown below:

Table 4: University of Oxford Stringency Index Example

Country	ISO	01jan2020	02jan2020	...	26sep2020
Sudan	SDN	0	0	...	57
Senegal	SEN	0	0	...	44
Singapore	SGP	0	14	...	52

4.1.5 Economic Data

The economic data can be downloaded directly from the *International Monetary Fund's 2020 World Economic Outlook Database* [22]. There is a wide variety of economic data that can be downloaded, but for research purposes, three key metrics have been selected: general government net lending/borrowing (percent of GDP), GDP (current prices in purchasing power parity), unemployment rate (percent of total labor force). The unemployment rate data was not available for every country. An example of this data is shown below:

Table 5: International Monetary Fund Economic Data Example

ISO	Country	Government Debt (Lending/Borrowing)	GDP (billions)	Unemployment Rate
DEU	Germany	1.867	4342.909	3.4
DJI	Djibouti	-2.782	5.723	
DMA	Dominica	-19.73	0.763	

4.1.6 Healthcare Data

The healthcare data comes from a *World Health Organization's* report titled *Measuring Overall health System Performance for 191 Countries* [23]. This report generated an index score for the quality of every country's healthcare system in terms of the quality of level, equity of distribution, and efficiency of health, responsiveness, and fairness in financing. An example of this data is shown below:

Table 6: WHO Healthcare Quality Data Example

Rank	Country	ISO	Index
1	France	FRA	0.994
2	Italy	ITA	0.991
3	San Marino	SMR	0.988

4.1.7 Press Freedom Data

The press freedom data can be copied from the *Reporters without Borders 2020 World Press Freedom Index* [24]. This index provides a countries rank, index score, and categorical classification. An example of this data is shown below:

Table 7: Press Freedom Index Data Example

Rank	Country	ISO	Score	Categorical Rank
14	Estonia	EST	12.61	Best
15	Iceland	ISL	15.12	Better
16	Canada	CAN	15.29	Better

4.2 Data Preprocessing

Now that the data sources have been found, there are a few steps that need to be taken before the actual analysis can begin. These steps are listed below:

1. Conversion to .csv files: To efficiently read in all the data files, all of them should be converted from their original format to .csv files. This will allow the utilization of fast and efficient data reading functions in python's *pandas* library.

2. ISO Labeling: Every country needs to have a unique identifier for the data analysis later on. Therefore, ISO labels must be added to the data files where they are absent.

3. Preliminary Data Selection: In the testing data file, there are a few countries that are tracked in two different ways. For example, both the number of tests given, and the number of people tested are independently tracked for Argentina. To keep things consistent, we must delete all records that are not total tests administered.

4. Deleting Unnecessary Data: In some data files, there are columns or rows of data that are unnecessary and can be deleted. For example, the testing data file has a column for sources. Although useful to know, this information is not needed for the data analysis and can be deleted.

5. Combining Like Data: In the cases and death data files, some countries' data is further broken down into states or provinces. Thus, to conduct analyses on the country-level, we must combine these data points into one country.

6. Reindexing Data: For later analysis, it will be helpful to have every file organized with data indexes corresponding to country ISO code.

4.3 Metric Generation

In this section, the different metrics that will be calculated from the COVID-19 case, death, and testing data will be detailed.

4.3.1 Total Cases

Total Cases represents the total number of cases to occur in any given country.

4.3.2 Total Deaths

Total Deaths represents the total number of deaths to occur in any given country.

4.3.3 Total Tests

Total Tests represents the total number of tests that any given country has administered.

4.3.4 Peak Stringency

Peak Stringency is the maximum score of the Stringency Index that a country reached.

4.3.5 Case to Death Ratio Average

Case to Death Ratio Average is calculated using the following equation:

$$\frac{TotalDeaths}{TotalCases} \tag{1}$$

4.3.6 Case to Test Ratio Average

Case to Testing Ratio Average is calculated using the following equation:

$$\frac{TotalCases}{TotalTests} \tag{2}$$

4.3.7 Total Cases Prior to Peak Stringency

Totals Cases Prior to Peak Stringency is a measure of the total number of cases that were recorded in a country prior to the Stringency Index reaching it's peak.

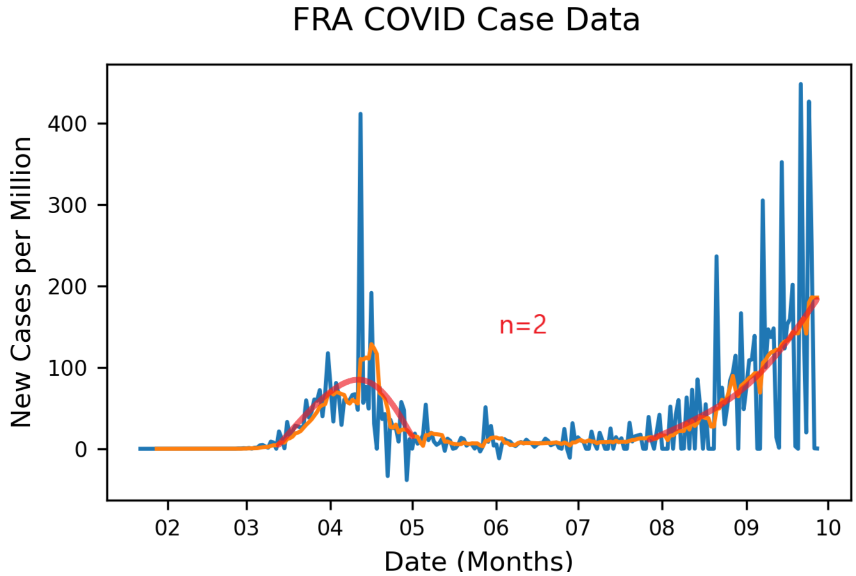
4.3.8 Total Deaths Prior to Peak Stringency

Totals Deaths Prior to Peak Stringency is a measure of the total number of deaths that were recorded in a country prior to the Stringency Index reaching it's peak.

4.3.9 Number of Outbreaks

Number of Outbreaks represents the number of distinct peaks in cases that occurred in a given country. This is determined by a country's cases distribution. An example is given in the figure below:

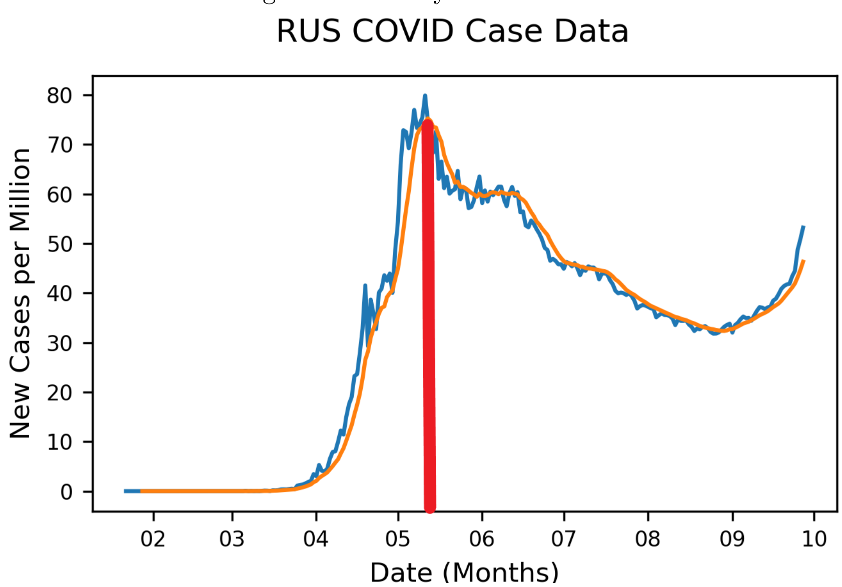
Figure 4: Number of Outbreaks



4.3.10 Severity of Initial Outbreak

Severity of Initial Outbreak is a measure of the peak number of cases experienced during a given countries first outbreak. An example is given in the figure below:

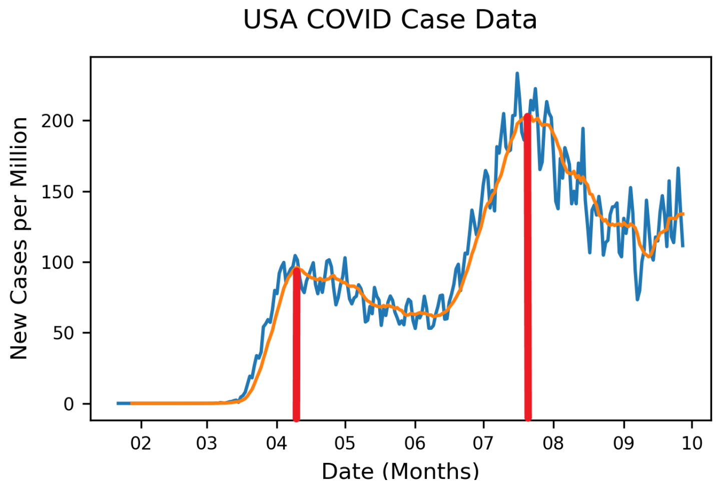
Figure 5: Severity of Initial Outbreak



4.3.11 Severity of Subsequent Outbreaks

Severity of Subsequent Outbreaks is a measure of the peak of subsequent outbreak compared to the peak of a countries initial outbreak. An example is given in the figure below:

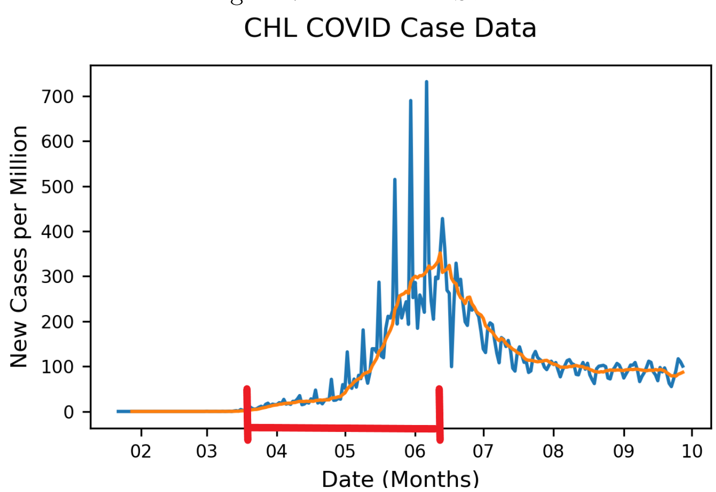
Figure 6: Severity of Subsequent Outbreaks



4.3.12 Time until Submission

Time until Submission measure the amount of time from the start of an outbreak until the peak of an outbreak. An example is given in the figure below:

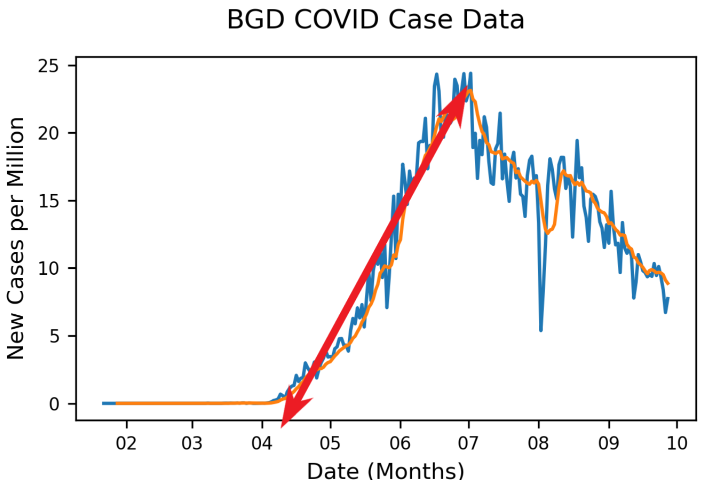
Figure 7: Time until Submission



4.3.13 Rate of Outbreak

Rate of Outbreak measures the rate of growth in the number of cases a country experienced during an outbreak. An example is given in the figure below:

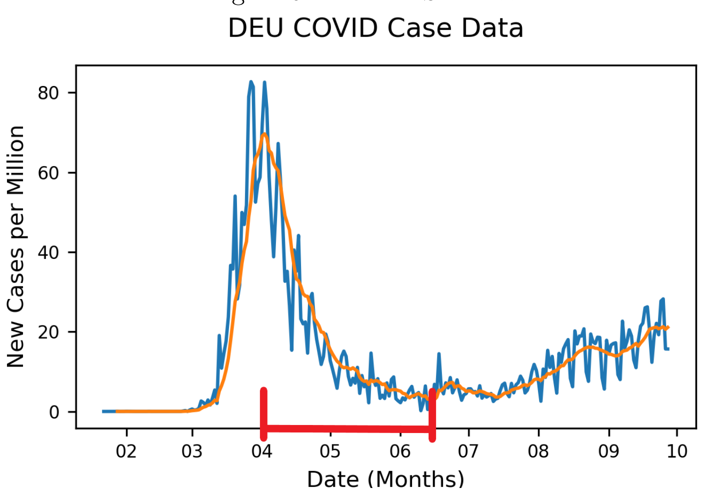
Figure 8: Rate of Outbreak



4.3.14 Time of Submission

Time of Submission measures the amount of time from the peak in cases until cases drop. An example is given in the figure below:

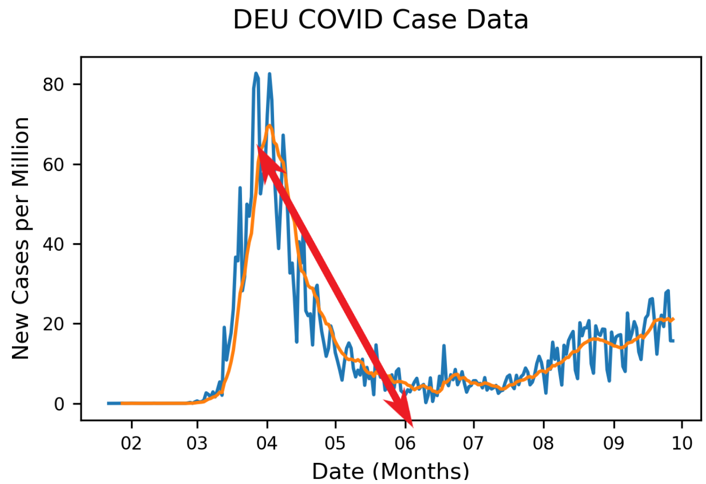
Figure 9: Time of Submission



4.3.15 Rate of Submission

Rate of Submission measures the rate of decrease in the number of deaths a country experienced during an outbreak. And example is given in the figure below:

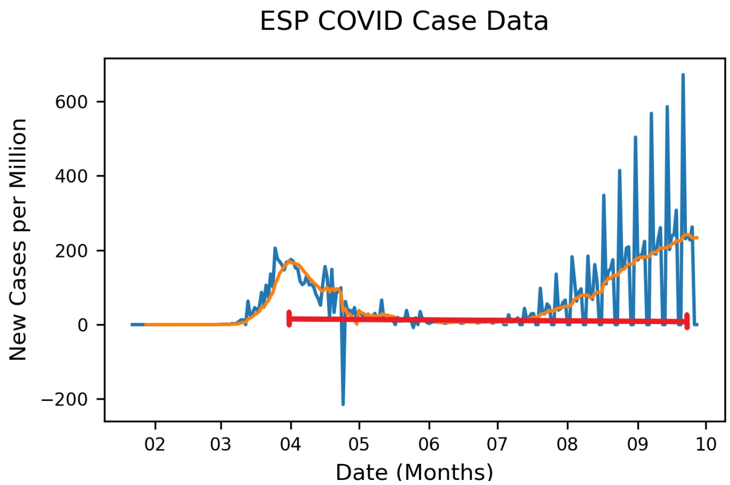
Figure 10: Rate of Submission



4.3.16 Length Between Outbreaks

Length between Outbreaks represents the amount of time between peaks of previous and subsequent outbreaks. And example is given in the figure below:

Figure 11: Rate of Submission



4.4 Analysis Methods

Due to the fact that both qualitative and quantitative metrics will be involved with the research, there are two main types of analyses that will be used to determine whether the relationships between two metrics are statistically significant or not: Regression Analysis and ANOVA Analysis.

4.4.1 Regression Analysis

"Simple linear regression allows us to look at the linear relationship between one normally distributed interval predictor and one normally distributed interval outcome variable" [25]. By performing a simple linear regression between two purely quantitative metrics (e.g. a country's pandemic preparedness score vs. the rate of their initial outbreak) a t-value and p-score for the relationship between the two will be generated. In the event the p-value is less than 0.05, it could be determined that the relationship between the two variable is statically significant. Additionally, with the regression analysis, an r^2 value would also be calculated which could be used to comment on the quality of the relationship as a whole.

4.4.2 ANOVA Analysis

"A one-way analysis of variance (ANOVA) is used when you have a categorical independent variable (with two or more categories) and a normally distributed interval dependent variable and you wish to test for differences in the means of the dependent variable broken down by the levels of the independent variable" [25]. By performing an ANOVA analysis on a level of a categorical variable and a quantitative variable (e.g. the categorical classification of a country's pandemic preparedness and their peak stringency index score) a F-score and a p-value will be obtained. Again, if the p-value is less than 0.05, the relationship between the categorical variable and the quantitative variable would be determined to be statistically significant.

5 Anticipated Problems and Proposed Solutions

In this section, anticipated problems will be outlined. Then, proposed solutions for each problem will be elaborated upon.

5.1 Data Equity

The issue about data equity comes from the following situation: all the COVID-19 case, death, and testing data is given in terms of number of people. If the data were analyzed without any modification, the analyses would show that nearly every country with a large population handled the COVID-19 pandemic worse than countries with small populations. Thus, a country's population should be considered a confounding variable that must be accounted for.

There is an easy way to do so: every country's COVID-19 case, death, and testing data needs to be considered in terms of frequency instead of the number of occurrences. For example, instead of considering the total number of COVID-19 cases a country had, the number of cases per million people should be considered. This would allow every country to be analyzed against one another while eliminating the confounding variable of population size.

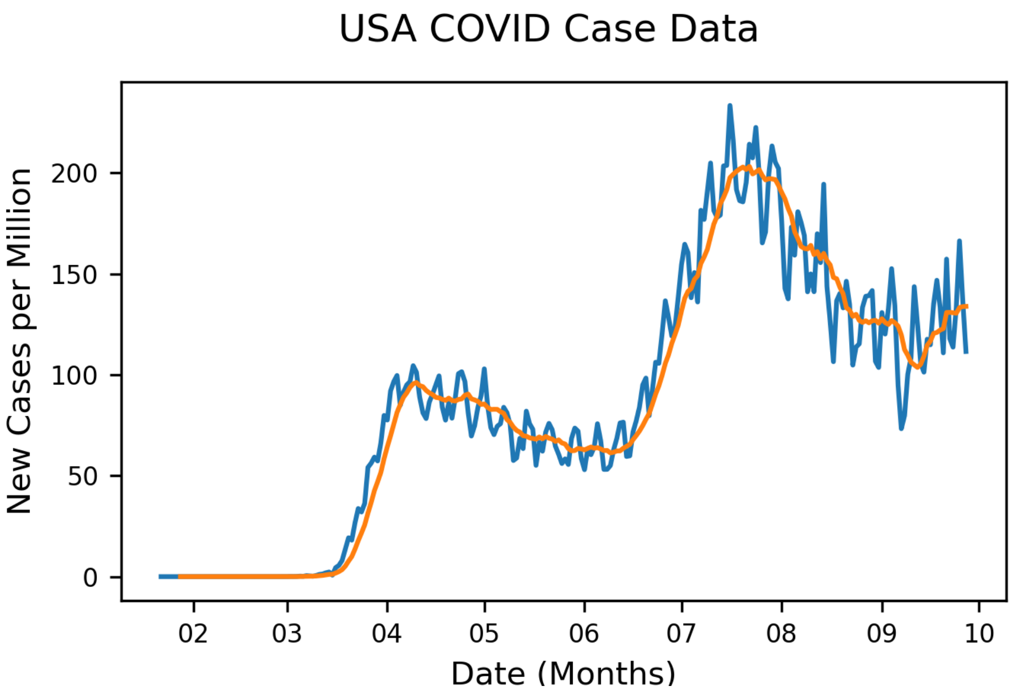
This conversion can easily be done as well. The *United Nations' 2019 World Population Prospect Report* provides the population of every single member country [26]. By taking the COVID-19 case, death, and testing data and dividing it by a factor of a country's population, we will get the number of COVID-19 cases, deaths, and tests per million people for every country can be obtained.

5.2 Describing and Smoothing Data

The issue about describing and smoothing data comes down the two factors: data periodicity and real-world data variability.

From looking at the COVID-19 case data for many countries, one will notice that the data seems to experience consistent periodicity throughout a given week (i.e. seven-day period). An example of this is shown below:

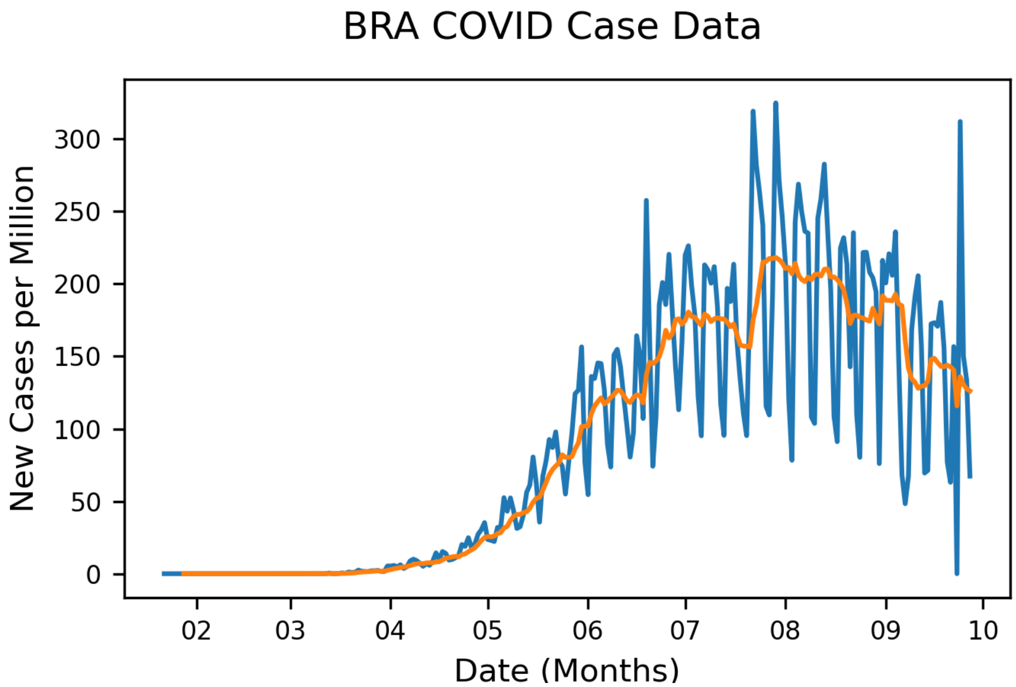
Figure 12: Periodicity of Data (USA)



The important thing to notice about this periodicity is that, due to it weekly nature, it can largely be smoothed by implementing a seven-day moving average. Accordingly, data periodicity issue can be solved by calculating a seven-day moving average to calculate the COVID-19 case, death, and testing metrics from.

However, there is still the matter of real-world data variability. Even with the introduction of a seven-day moving average, the COVID-19 case, death, and testing curves may not be smooth enough to perform data analysis on. For example, consider the COVID-19 case graph below:

Figure 13: Real-World Data Variability (Brazil)



From the graph above, one can see that even with the addition of a seven-day moving average, the data still does not have a smooth curve. For example, it would appear that Brazil experienced one main outbreak, however there are four instances where cases drop for a period of time and then rose again.

These patterns are found in many countries' COVID-19 case, death, and testing data. Furthermore, it would be inefficient, and begin to negatively affect, the quality of the statistical analyses performed if this problem were to be solved by implementing longer and longer moving averages to smooth the data for every country.

The best solution would be to take the COVID-19 case, death, and testing data in the form of seven-day moving averages and then fit them to a nonlinear function. Then, the resulting nonlinear function could be used for the calculation of the COVID-19 metrics. This approach has two main benefits:

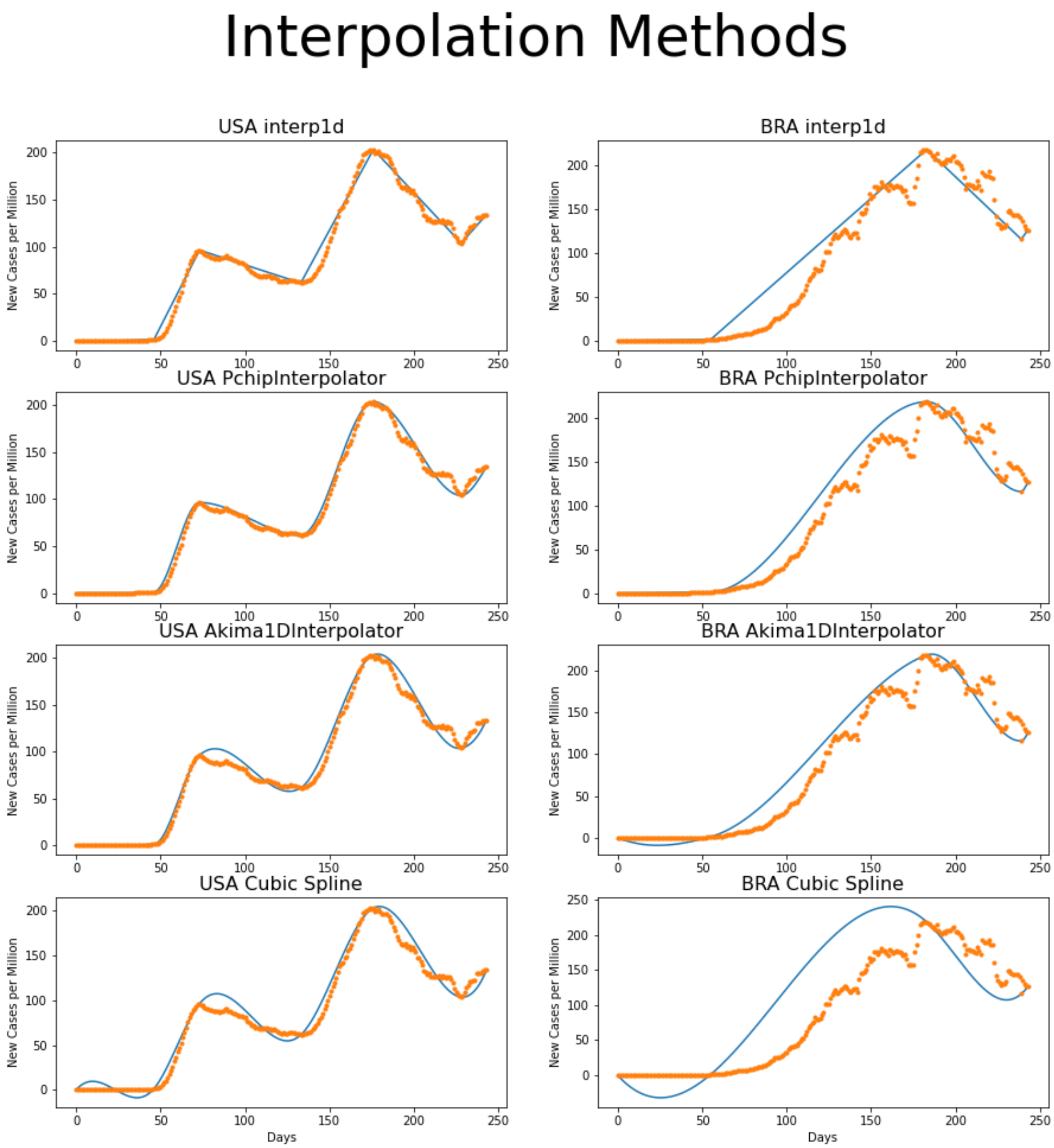
1. It would provide a systematic and repeatable way to generalize all of the data.
2. The resulting nonlinear function, through its derivatives, would provide inflection points that would delineate when secondary outbreaks occurred, their peaks, etc.

There are four main interpolation algorithms that could best be used to create nonlinear functions based on a country's seven-day moving average: *interp1D*, *Piecewise Cubic Hermite Interpolating Polynomial (Pchip)*, *Akima Interpolator*, and *Cubic Spline*. What makes each of these interpolation methods viable is they all have derivatives or easy methods to calculate their derivatives. The specifics of each method are outlined below:

- interp1D: "x and y are arrays of values used to approximate some function f: y = f(x). This class returns a function whose call method uses interpolation to find the value of new points" [27].
- Pchip: "x and y are arrays of values used to approximate some function f, with y = f(x). The interpolant uses monotonic cubic splines to find the value of new points. The interpolator preserves monotonicity in the interpolation data and does not overshoot if the data is not smooth. The first derivatives are guaranteed to be continuous, but the second derivatives may jump at x_k" [27].
- Akima Interpolator: "Fit piecewise cubic polynomials, given vectors x and y. The interpolation method by Akima uses a continuously differentiable sub-spline built from piecewise cubic polynomials. The resultant curve passes through the given data points and will appear smooth and natural" [27].
- Cubic Spline: Interpolate data with a piecewise cubic polynomial which is twice continuously differentiable. The result is represented as a PPoly instance with breakpoints matching the given data" [27].

Below is a figure that plots the result of the four different interpolation methods over the seven-day moving averages of the USA's and Brazil's COVID-19 case data. It uses a basic algorithm that finds the local maximums and minimums of the seven-day moving average data with a 30-day moving window. It also includes the start and endpoints of the data. Finally, the first point where cases exceed one per million is also included. This figure is by no means a finalized method, but should serve as a proof of concept for the validity of at least one of the interpolation methods.

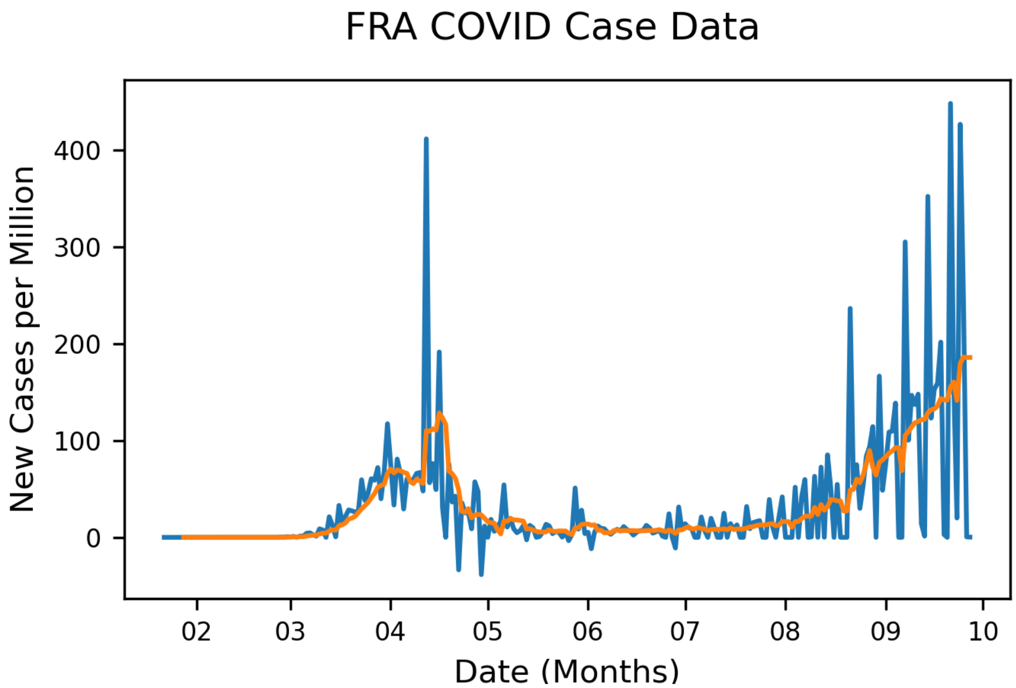
Figure 14: Interpolation Methods - Proof of Concept



5.3 Handling Outliers

Many countries retroactively added or retracted COVID-19 cases or deaths from their running totals over the course of the pandemic. An example of this is shown below:

Figure 15: Outliers (France)



As one can see with France's COVID-19 case data, it would appear that many cases were added in mid-April and that on two occasions the number of new cases was negative in late-April. While the addition in mid-April visibly impacts the seven-day moving average, the days where the number of new cases are negative (i.e. cases are subtracted from the total) clearly do not make sense.

Unfortunately, there is no good way to get rid of such outliers algorithmicly. As the plot of France's COVID-19 cases shows, differentiating an outlier (mid-April) from the large case fluctuations due to data periodicity (September and October) would be difficult. However, Johns Hopkins (the source of the case and death data) keeps track of such instances where backlogs of cases/deaths are added or removed from the data sets. Thus, there is a record of these outlier cases that will need to be handled manually.

5.4 Data Accuracy and Availability

One of the biggest questions when it comes to COVID-19 data is its accuracy and availability. For example, Argentina and Sudan both have similar populations (45.3 million and 44.1 million respectively), but Argentina has reported nearly 60-times more cases than Sudan (798,486 vs. 13,653). Two possible conclusion could be drawn from this:

1. Sudan handled the COVID-19 pandemic nearly 60-times better than Argentina.

2. Sudan under-reported their COVID-19 data.

The more likely conclusion is Sudan under-reported their COVID-19 data. This could be for a variety of reasons ranging from the ability of a country's healthcare system to test many people to deliberate manipulation (not to claim that sudan has done so). The exact cause does not matter, but what does matter is that the accuracy of the data cannot be assured to be the best. There are two ways to account for this.

Firstly, by leveraging the COVID-19 case, death, and testing data against the other metrics (i.e. economic data, healthcare quality data, press freedom) one can hope to identify confounding variables that may better explain the COVID-19 data. For example, if one were to find that GDP was significantly correlated to the calculated COVID-19 metrics, it could indicate that the data is biased. Identifying these factors will help put the results in context so that they can still be useful for future strategic supply chain decision making.

Secondly, by admitting that there will be irreconcilable problems with the underlying COVID-19 data. However, performing our research and analysis is still beneficial because it is better than performing no analysis at all and not bringing a quantitative element into consideration when it comes to accounting for pandemic preparedness when making future strategic supply chain decisions is not a valid option.

A combination of both these methods is the most useful. One must accept that the COVID-19 case, death, and testing data will be flawed, but performing research on it is still valuable and necessary. Furthermore, by comparing it against other potential confounding metrics, it can place the results of the research within the necessary context in which to properly consider the results.

6 Schedule of Thesis Writing

Month	Task
October	Write/Present Proposal and finish data processing in python
November	Write Metric Generation Code
December	Finish Metric Generation Code and Start Statistical Analysis Code
January	Finish Statistical Analysis Code and Begin Conclusions Discussions
February	Add Additional Metrics or Create Own Pandemic Preparedness Rankings
March	Buffer Month for if Problems Emerge
April	Combine all Works into Final Thesis
May	Submit Thesis
June	Final Defense
July	Graduate

References

[1] Jessica Boyd and Institute for Supply Management. COVID-19 Global Supply Chain Disruptions Continue, April 2020. publisher: Cision Distribution.

[2] Michael Wilson. Why COVID-19 is Different from Other Supply Chain Disruptions, September 2020. publisher: AC Business Media, LLC.

[3] Fred Schmalz and Kellogg Insight. The coronavirus outbreak is disrupting supply chains around the world —here's how companies can adjust and prepare, March 2020. publisher: Insider Inc.

[4] Global Preparedness Monitoring Board. A world at risk: annual report on global preparedness for health emergencies. *Geneva: World Health Organization; 2019. Licence: CC BY-NC-SA 3*, 0, 2019.

[5] The World Bank. The Global Economic Outlook During the COVID-19 Pandemic: A Changed World, June 2020. publisher: World Bank Group.

[6] Henry Ridgwell. Japan Tsunami Damage Cost Could Top $300 Billion, March 2011. publisher: Global Security.

[7] Jonathan M. Samet and Joann Seo. The Financial Costs of the Chernobyl Nuclear Power Plant Disaster: A Review of the Literature. Technical report, April 2016.

[8] Knut Alicke and Anna Strigel. Supply chain risk management is back, January 2020. publisher: McKinsey & Company.

[9] Xin Gu, Shan Ying, Weiqiang Zhang, and Yewei Tao. How do firms respond to covid-19? first evidence from suzhou, china. *Emerging Markets Finance and Trade*, 56(10):2181–2197, 2020.

[10] Wei Liu, Xiao-Guang Yue, and Paul B. Tchounwou. Response to the covid-19 epidemic: The chinese experience and implications for other countries. *International Journal of Environmental Research and Public Health*, 17(7), 2020.

[11] Guiyang Zhu, Mabel C. Chou, and Christina W. Tsai. Lessons learned from the covid-19 pandemic exposing the shortcomings of current supply chain operations: A long-term prescriptive offering. *Sustainability*, 12(14), 2020.

[12] Dabo Guan, Daoping Wang, Stephane Hallegatte, Steven J. Davis, Jingwen Huo, Shuping Li, Yangchun Bai, Tianyang Lei, Qianyu Xue, D'Maris Coffman, Danyang Cheng, Peipei Chen, Xi Liang, Bing Xu, Xiaosheng Lu, Shouyang Wang, Klaus Hubacek, and Peng Gong. Global supply-chain effects of covid-19 control measures. *Nature Human Behaviour*, 4(6):577–587, Jun 2020.

[13] Sunil Chopra and ManMohan S Sodhi. Reducing the risk of supply chain disruptions. *MIT Sloan Management Review*, 55(3), 2014.

[14] Maciel M. Queiroz, Dmitry Ivanov, Alexandre Dolgui, and Samuel Fosso Wamba. Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the covid-19 pandemic through a structured literature review. *Annals of Operations Research*, Jun 2020.

[15] Richard Baldwin and Eiichi Tomiura. *Thinking Ahead about the Trade Impact of COVID-19*, page 59–71. Centre for Economic Policy Research, 2020.

[16] Alain Verbeke. Will the covid-19 pandemic really change the governance of global value chains? *British Journal of Management*, 31(3):444–446, Jul 2020. PMC7361413[pmcid].

[17] Hongzhi Gao and Monica Ren. Overreliance on china and dynamic balancing in the shift of global value chains in response to global pandemic covid-19: an australian and new zealand perspective. *Asian Business & Management*, 19(3):306–310, Jul 2020.

[18] Ensheng Dong, Hongru Du, and Lauren Gardner. An interactive web-based dashboard to track covid-19 in real time. *The Lancet Infectious Diseases*, 20(5):533–534, May 2020.

[19] Esteban Ortiz-Ospina Max Roser, Hannah Ritchie and Joe Hasell. Coronavirus pandemic (covid-19). *Our World in Data*, 2020. https://ourworldindata.org/coronavirus.

[20] The Global Health Security Index.

[21] Thomas Hale, Noam Angrist, Emily Cameron-Blake, Laura Hallas, Beatriz Kira, Saptarshi Majumdar, Anna Petherick, Toby Phillips, Helen Tatlow, and Samuel Webster. *(2020).* Oxford COVID-19 Government Response Tracker, Blavatnik School of Government.

[22] International Monetary Fund. World economic outlook, april 2020: The great lockdown, 2020.

[23] Ajay Tandon, Christopher JL Murray, Jeremy A Lauer, and David B Evans. Measuring overall health system performance for 191 countries. *Geneva: World Health Organization*, 2000.

[24] 2020 World Press Freedom Index | Reporters Without Borders.

[25] J. Bruin. newtest: command to compute new test @ONLINE, February 2011.

[26] UN Desa. World population prospects 2019: Highlights. *New York (US): United Nations Department for Economic and Social Affairs*, 2019.

[27] Interpolation (scipy.interpolate) —SciPy v1.5.2 Reference Guide.