The impact of maritime trade disruptions on food security: the case of imported calories

by

Jenae Noelle Tilford

B.S., Kansas State University, 2023

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Economics
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2025

Approved by:

Major Professor
Nelson Villoria, Ph.D

Copyright

Abstract

World trade is heavily dependent on maritime travel of goods and services (Brancaccio, et al. 2020; UNCTAD, 2024; Wang, et al., 2024). Key maritime passageways, such as the Panama Canal, the Strait of Gibraltar, the Turkish Straits, the Suez Canal, and the Strait of Malacca, facilitate global shipping but often face heavy congestion (Bailey and Wellesley, 2017). More than fifty five percent of internationally traded maize, wheat, rice, and soybeans are shipped through at least one maritime chokepoint (Bailey and Wellesley, 2017). Within recent years, there has been an increasing number of global supply chain disruptions that have grown in magnitude and frequency straining trade routes and impacting food availability and prices.

This paper evaluates which countries face the greatest risks to their food supplies when ships can no longer utilize the Panama Canal, the Suez Canal, or the Malacca Strait due to temporary disruptions. The empirical strategy is to elicit country-by-country changes in imports of calories embodied in maize, wheat, and rice when one of the focus chokepoints experiences a disruption. To do this, the gravity model effectively captures changes in trade between countries (Head and Mayer, 2014; Pfaffermayr, 2023; Yotov, et al., 2016). The analysis uses bilateral trade data from FAOSTAT and is converted to calories using conversion factors, also from FAO. Dyadic covariates (e.g., trade agreements) are provided by the USITC Gravity Portal Trade and Production Database and the CEPII Gravity Database, and coordinates of major ports in each country are sourced from the World Port Index of the Geospatial-Intelligence Agency (2019). The coordinates are used as inputs in the maritime routing tool Searoute (Gaffuri 2024) which computes the shortest maritime route following the path of the most used shipping routes published in the Oak Ridge National Labs' Global Shipping Lane Network (2000). One gravity model was constructed and used to evaluate four scenarios. One baseline and three

counterfactuals reflecting the absence of specific chokepoints. The gravity models are fitted with data for the years 2010-2022.

The results show for every 1% increase in distance between two countries, leads to a 1.19% decrease in imported calories for the receiving country. Among the countries included in this analysis, El Salvador experienced the largest change in imported calories when the Panama Canal was unavailable, with a 62.00% decrease. When the Suez Canal was inaccessible, Jordan saw an 81.36% reduction in imported calories. The removal of the Malacca Strait from shipping routes resulted in a 19.87% decrease in imported calories for Malaysia.

While this paper solely focuses on a few specific maritime chokepoints, there are many other chokepoints along the agricultural and food supply chains that prevent countries from having open access to food---thus the analysis provides a building stone for more complex analysis. More generally, this analysis sheds light on the importance and need of collaboration amongst international countries and governments to protect these chokepoints and reduce pressure on these critical trade routes.

Table of Contents

List of Figures

List of Tables

Acknowledgements

This research would not have been possible without the guidance, support, and encouragement of several individuals to whom I owe many thanks to. First and foremost, my deepest and utmost gratitude to my major professor, Dr. Nelson Villoria. Thank you for your encouragement and guidance. You always listened to my ideas and concerns with a patient ear. You have been instrumental throughout my degree and on the work of this project. It would not have happened without you. Thank you for the time and energy you invested in me.

Thank you to my committee members, Dr. Nathan Hendricks and Dr. Glynn Tonsor, for your patience and willingness to be a part of this work. Thank you for all of the expertise and time you have dedicated to this work and for the revisions during this project. I have the deepest appreciation for you and the time you have invested into me.

Thank you to Dr. Rich Llewelyn and Dr. Andrew Barkley for being some of the first people to spark my interest in pursuing a Masters degree. Both of your classes and conversations outside of class were instrumental in my decision and provided me with a valuable toolbelt of skills to carry with me through life. I appreciate you for challenging and pushing me to grow beyond my coursework.

Thank you to Dr. Kristyn Jones for the guidance and support in cultivating my passion for agriculture. Without your time, dedication, and investment into me as a person I would not have pursued a degree and career in agriculture. You were foundational in igniting this spark and are a huge inspiration to me as a person and advocate for agriculture.

To my cohort and friends, thank you for the unwavering support and camaraderie. I will look back on these times fondly because of you all. This degree was difficult at times, but you

lightened the load. Thank you to every mentor, coach, teacher, and professor that took a chance on me and molded me into the person I am today. I am eternally grateful to you all.

Lastly, I want to acknowledge my family and their support. To Mom, Dad, Travis, and Jordan, I am eternally blessed to call you my family and I am deeply grateful for all the steadfast love, encouragement, support, and patience. You are all my role models and a source of inspiration and motivation for me daily.

Dedication

This thesis is dedicated to my family. They showed me my agricultural roots and never let me forget that I always have a place to call home. To my past relatives who braved the unknown to pioneer and started a homestead farming and raising horses in western Nebraska, I am proud to hail from their determination and love. To both my grandparents for teaching me about the legacy of family and the importance of hard work and always making the most of any circumstance. The outpouring of love into both your families has proven to me that I can always be a light for others even in the darkest of times.

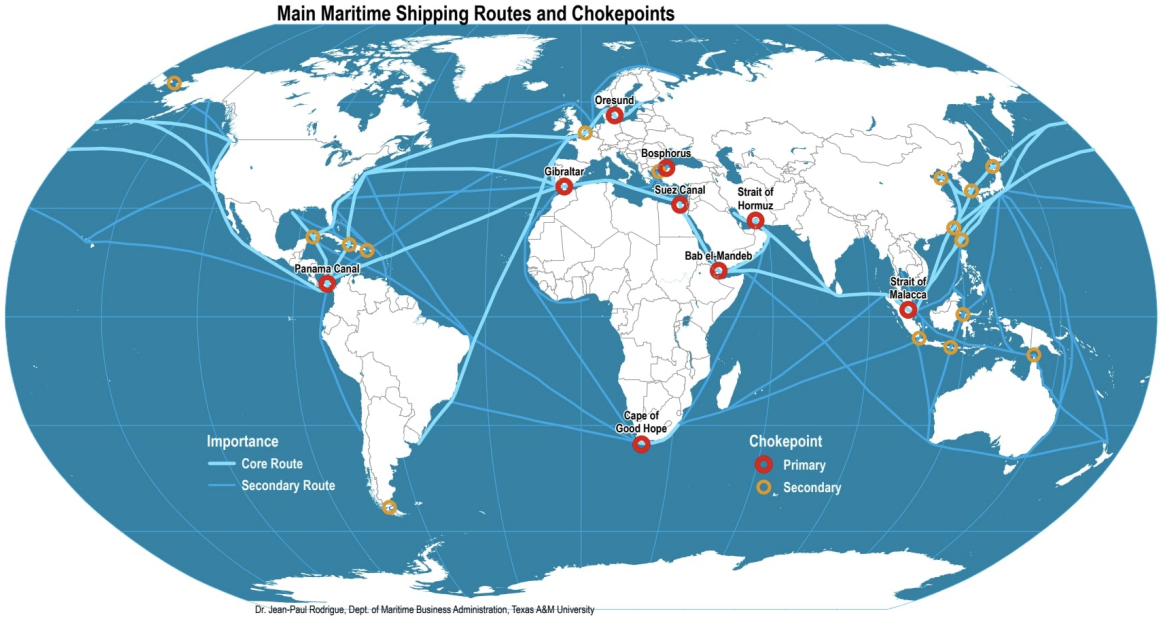
Chapter 1 - Introduction

World trade is heavily dependent on maritime shipping to transport products around the globe. Approximately, 93,000 merchant ships and 1.25 million seafarers transport nearly six billion tons of cargo accounting for more than 80% of world trade volume and about 70% of world trade value (Brancaccio, Kalouptsidi and Papageorgiou 2020; He et al. 2023). Without shipping by sea, trade would not be as efficient and would cost more for countries further apart from one another. To cut distances between countries and regions of the world, canals and straits are a vital maritime structure that makes it easier and faster for ships to reach destinations. Without any one of these structures and waterways, world trade would look dramatically different, and the supply of products would be more volatile. Brancaccio, et al. (2020), states that "the market for shipping services can influence trade flows, the products countries sell abroad, and the way in which price shocks reverberate through trade." With many ships traveling through these canals and waterways, there is an even larger volume of cargo, worth millions of dollars, passing through these channels every day. These channels help to facilitate trade but often face heavy congestion.

Key maritime passageways such as, the Panama Canal, the Strait of Gibraltar, the Dover Strait, the Turkish Straits, the Suez Canal, the Strait of Bab al-Mandab, the Strait of Hormuz, and the Strait of Malacca are essential to the global food system (Bailey and Wellesley 2017). When one of these channels faces a disruption or closure at any given time or for any duration, the impact causes global ripples. Due to the large volume of trade through these passageways, there is often congestion within these corridors. A chokepoint is defined as an area of congestion along a [trade] route (Bailey and Wellesley 2017). Many of these chokepoints provide the shortest maritime routes between countries. For example, the Suez Canal is a waterway that connects the

Mediterranean Sea to the Red Sea (Lee and Wong 2021) and provides the shortest maritime route between Europe and countries around the Indian and western Pacific Ocean (Smith and Fisher 2024). Foreign trade for several East African countries is highly dependent on the Suez Canal. Approximately 31% of foreign trade by volume for Djibouti, 15% of trade for Kenya, 10% of trade for Tanzania, and 34% of trade for Sudan is channeled through the Suez Canal (United Nations Trade and Development 2024). The Panama Canal is also vital to countries on the West Coast of South America and connecting the eastern coast of the United States and Asia (United Nations Trade and Development 2024). Approximately 22% of total Chilean and Peruvian foreign trade volumes depend on the Panama Canal and Ecuador is thought to be the most dependent on the Panama Canal with 26% of its foreign trade volumes crossing the canal (United Nations Trade and Development 2024). In 2022, the Panama Canal served as the primary route for 57.5% of the total cargo transported in container ships from Asia to the Eastern coast of the United States (Panama Canal Authority 2023). These main waterways and channels are susceptible to disruptions, forcing closure for a brief period of time or for ships to find alternative routes to the same destination (Bailey and Wellesley 2017). Below is a map of all chokepoints identified by (Notteboom, Pallis and Rodrigue 2021) used in (Bailey and Wellesley 2017).

Figure 1.1 Maritime, coastal and inland chokepoints and major shipping routes



Source: Rodrigue, J.-P., Notteboom, T., Pallis, A. (2022), *Port Economics, Management and Policy*, New York: Routledge, https://porteconomicsmanagement.org/pemp/contents/part1/interoceanic-passages/main-maritime-shipping-routes/.

When a chokepoint experiences a disruption, the other chokepoints become heavily stressed due to more traffic rerouting from the original chokepoint or experiencing other repercussions from the disruption. If the chokepoints are situated in relative proximity to each other, they may be exposed to the same localized risks, meaning that their risk of closure is likely to be co-dependent (Bailey and Wellesley 2017). Low-income food-deficit countries are most vulnerable to chokepoint disruption. However, three of the world's biggest 20 economies by GDP (Japan, South Korea, and Saudi Arabia) are on the list of countries most exposed to chokepoint disruption risk and a few high-income food-deficit countries (such as, Japan and South Korea) also rank among the most exposed to chokepoint disruption (Bailey and Wellesley,

2017). Import dependency does not necessarily imply a high degree of direct exposure to chokepoint disruption if imports do not rely on key chokepoints. However, there still may be indirect chokepoint risk through interconnectedness (Bailey and Wellesley, 2017).

Looking specifically at how reliant the agricultural sector is dependent on maritime chokepoints, the annual throughput of major grain commodities in chokepoints has increased significantly. Several of the notable passageways like the Panama Canal, the Turkish Straits, the Suez Canal, and the Strait of Malacca experienced a growth from 25 million tonnes of annual throughput of major grains in 2000 to more than 50 million tonnes in 2015 (Bailey and Wellesley 2017). The volume of cargo being transported through these areas has grown and chokepoints continue to be strained when disruptions occur. This occurrence can cause major delays and shortages of goods in markets.

If a ship must avoid a chokepoint, there is an increase in transportation costs of goods between countries because of additional distance, time, and resources needed to reach the same destination. Alternative routes that are a longer distance add costs, including resourcing and fuel bills, and the risk of time-sensitive freight being delayed or spoiled (New Zealand Embassy (Cairo) 2021). A cargo ship traveling from a Southern Chinese port to Rotterdam, Netherlands using the Suez Canal is 10,000 nautical miles (Brigham 2021). The canal remains the fastest and most direct maritime trade link between Asia and Europe (New Zealand Embassy (Cairo) 2021). Alternatively, for the same locations, but traveling around the Cape of Good Hope (in Africa), an alternative shipping route; the distance is 13,500 nautical miles (Brigham 2021). The journey from the Suez Canal (Egypt) to Rotterdam (Netherlands) takes about 11 days but to travel around the Cape of Good Hope (in Africa), adds about 26 more days for the same destination (Goodman and Reed 2021). When a chokepoint location is unavailable for use to travel, this will drastically

impact trade flows. In (Sandkamp, Stamer and Yang 2022), the authors make note of previous estimations by (Bendall 2010), that calculate the costs of re-routing ships from the Suez Canal to the Cape of Good Hope and found that it would cost about $3.2 million USD for a large crude carrier. Another prominent study, by (Brancaccio et al. 2020), found that taking the Suez Canal out of commission reduced world trade by 3.5% and up to a 26% decline in trade in the Middle East. Different types of cargo carriers also affect how quickly a ship can make the journey based on weight, size, and speed of the carrier.

The transport industry is vital to feeding the world and connecting countries to one another. Many countries' wealth can come from trade and is often crucial to their economy's growth and overall societal wealth and development. When the distribution network connecting countries and goods across the globe is disrupted there can be major implications for producers, consumers, and all stakeholders within the system and the global value chain. History has recorded many events that have disrupted trade and caused complications for people across the world.

These instances highlight that all things involved in production, consumption, transportation, and regulations applying to food is complex. It is not just one factor that takes care of all those previously mentioned, but many factors that can be explained in a systems approach (Brock 2023) and can be commonly referred to or defined as a food system. This term can mean many things depending on the context or perspective of an individual. An analogy can be used to describe how the food system is defined in this paper. The food system can be compared to a car engine. There are many moving parts that work simultaneously to make the car run. Parts vary in size and in this case, new developments and technology can be added to this "engine". Usually, this engine can run smoothly but when one "part" or component of the

engine is disrupted or breaks, this can cause other parts of the engine (system) to also break or underperform. Each part of the food system has a push and pull reaction to other moving parts. When one part of the food system experiences significant change, there is a reaction in other parts of the system. Within this paper, the focus is on the supply chain "part" of the global food system. Within a supply chain there can be bottlenecks and disruptions. Typically, disruptive threats to the food system chokepoints fall under three categories: weather and climate, security and conflict, and political and institutional hazards (Bailey and Wellesley 2017). Recently, we've seen disruptions within the food system from the COVID-19 pandemic, the Russia-Ukraine conflict, the blockade of the Suez Canal by the *Ever Given* container ship, piracy along major trade routes in the Middle East, and low water levels in the Panama Canal. Researchers studying the impact of the COVID-19 global pandemic found that the pandemic decreased world trade by 7.0-7.4% in 2020 relative to 2019 (U.S. International Trade Commission 2020; Liu, Ornelas and Shi 2022). Others found that in 2020, global trade fell by 8.9% and was the steepest drop since the global financial crisis (Dickinson and Zemaityte 2021).

The Russia-Ukraine war decreased world trade by 1% and global GDP by 0.7% (Ruta 2022). Exports from Ukraine fell by 47.3% until August 2022 and have slowly recovered since then (Steinbach 2023). Russia maintained a blockade of exports from Ukraine by holding control of the Black Sea. Ukraine lost $19.4 billion USD in exports, while Russia gained $68.3 billion from the conflict (Steinbach 2023). Low-income and lower-middle-income countries suffered the most from this conflict. These countries received 20% less grain exports from Ukraine (as of January 2023) (Kilfoyle 2023). This war has had a long-lasting impact on food security for many countries dependent on exports out of the Black Sea.

When the large container ship *Ever Given* was lodged sideways in the Suez Canal, it created a blockade for six days preventing ships from entering or exiting the canal and 15% of the world's container capacity was affected (Goodman and Reed 2021; Russon 2021). Approximately 12% of global trade and 30% of global container traffic traverse the Suez Canal, transporting over $1 trillion USD worth of goods per year (New Zealand Embassy (Cairo) 2021). With those numbers, over 50 cargo ships travel through the canal daily carrying between $3-9 billion USD (New Zealand Embassy (Cairo) 2021). Many ships enroute to use the Suez Canal needed to either reroute or incur late fees for waiting at the entrance of the canal while the Suez Canal Authority worked to dislodge *Ever Given*. Both options were expensive for shipping companies and owners of the cargo onboard these ships. Delays in products swiftly followed. Analysts believed delays could still create congestion at major global trade hubs even after the dislodgement. Countries like Singapore, Malaysia, Saudi Arabia and the Netherlands were suspected to experience the most congestion as a result, due to disruptions to shipping schedules (New Zealand Embassy (Cairo) 2021). Late fees for cargo ranged from $15,000-$30,000 per day and additional fuel charges for rerouting were generally more than $30,000 per day, depending on the vessel type, but could cost more than $800,000 (Goodman and Reed 2021). The delays in trade cost billions of dollars to companies and further exacerbated supply shortages from the COVID-19 pandemic (Brancaccio et al. 2020).

Pirates are another threat to the transportation industry and have caused disruptions repeatedly over time. Shipping carries 90% of international commerce and as major shipping routes take cargo ships through narrow bodies of water, such as the Strait of Malacca and the Gulf of Aden, this provides an ideal opportunity for pirates to attack (Bendall 2010). According to the Suez Canal Authority, canal traffic has dropped by 50% since the surge in piracy (He et al.

2023; Bendall 2010). Still present today, there are quite a few attacks annually. In 2024, there were 116 pirate attacks and attempts at attacking (ICC International Maritime Bureau 2025). For the past five years the number of attacks annually ranges from 115-195 attempts and attacks (ICC International Maritime Bureau 2025). The number of pirate attacks ebbs and flows throughout the years and the nature of piracy attacks has changed over time but there is still the threat present of an attack, and each time it comes at a detrimental cost. Captured vessels are typically held on average for three months before a ransom, which averages $1 million, can secure the vessel and crew release (Costello 2008). Ransoms are what the pirates use to make money. It was estimated that in 2008 Somalian pirates had amassed over $100 million in ransom payments (Gettleman 2009). As a risk management tool, insurance is an option. But that also proves to be very expensive for companies. One of the biggest marine insurance payouts was around $70 million in an attack by pirates off Yemen in 2002 (Bendall 2010). Not only are pirate attacks detrimental to companies but they are also a loss to countries and consumers around the world. In 2010, the loss of trade disruption due to pirates was $18 billion USD (He et al. 2023) and over ten years (2000-2010), Somalian piracy reduced bilateral trade passing through the Gulf of Aden by 1.7-1.9% per year (Burlando, Cristea and Lee 2015). The European Union and five other countries are credited with shouldering 70% of the costs from piracy (Burlando et al. 2015). The costs of ransoms and damages to ships could increase transportation costs. These costs are pooled across the industry through insurance (Besley, Fetzer and Mueller 2015).

Another vital canal is the Panama Canal which is a critical element in the global supply chain particularly for the U.S. East Coast to Asia as well as Europe to U.S. West Coast and Canada routes (Bird 2024). The canal is man made and has been operational since 1914 (PCA (Panama Canal Authority) 2024) and accounts for 5-6% of global trade (Eavis and Angarita

2023; Bird 2024). In 2022, 14,000 vessels carrying more than 581 million tons of cargo (Feingold 2023; Bird 2024) passed through the canal. There have been very few closures of the Panama Canal but recently there have been concerns about the water levels in the canal preventing certain sized ships from using the canal in their journeys. The canal uses a system of locks that function as water lifts to raise and lower ships from one side to the other. To do this, the canal relies on a steady level of water in Gatun Lake (the reservoir of the canal), which also serves as a supply of drinking water for more than half the population of Panama (Larsen 2019). Panama has been prone to droughts resulting from El Niño phenomenon. The Chief Executive from Avance Gas, Oystein Kalleklev, said the drought was "the worst we have seen in terms of disruptions" (Eavis and Angarita 2023). El Niño brings warmer water to the central and eastern tropical Pacific Ocean which leads to a lack of precipitation, and a subsequent decline in the water level in Gatun Lake, even during the rainy season (Chico et al. 2024; Eavis and Angarita 2023). With these events occurring, the Panama Canal Authority must impose various transit capacity restrictions for the canal limiting the number and the size of ships allowed passage. Before the water issues, as many as 38 ships per day moved through the canal (Eavis and Angarita 2023). In July (2023) the Panama Canal Authority cut the average to 32 vessels, and the following week announced new limits that are likely to lead to fewer than 30 passages a day (Eavis and Angarita 2023). Restrictions on the ability of ships to use the canal will have an impact on countries that rely on the canal for most of their trade. While these restrictions have been important in conserving water levels within the canal, they have inevitably created congestion and a bottleneck of ships in the Panama Canal (Bird 2024). Currently, the Panama Canal Authority implemented an auction system allowing companies to bid for priority passage, allowing their ships to skip ahead of other ships waiting to be let through the canal. In August of

2022, Avance Gas paid $2.4 million to skip the long waiting line (Bird 2024; Eavis and Angarita 2023). In Panama, a lack of water has hampered canal operations in recent years, and some shipping experts say vessels may soon have to avoid the canal altogether if the problem gets worse (Eavis and Angarita 2023). All these events previously mentioned have decreased global trade and put pressure on key maritime passageways while forcing transportation companies to incur large costs.

This thesis evaluates which countries face the greatest risks to their food supplies when ships can no longer utilize the Panama Canal, the Suez Canal, or the Strait of Malacca due to temporary disruptions. The objective is not to predict the effects of a specific passageway closure but to help in understanding the heterogeneity in geographic patterns and the impacts of maritime passageway closures. This paper is a novel contribution to understanding the vulnerability of global food supply chains on global food security. A recent focus of our profession highlights the need to consider supply change linkages to understand the resilience of supply changes to different shocks (Zilberman et al. 2023; Barrett et al. 2022). This paper is a first attempt to understand the role of maritime disruptions in global food security.

The paper's structure will first lead into the role of trade in food security. Then transition into the theory behind the gravity trade model. Then lead into the components of the gravity model used to set up a fixed effects gravity regression that conducts four analyses. One is a baseline model and three are counterfactual models each with one maritime passageway unavailable for use. Following the model set up, the next section will be a description of the data used and the corresponding results of the regression. Lastly, the paper will conclude with the summary of the gravity model scenarios and limitations of the analysis.

Chapter 2 - Literature Review

Trade allows countries and people to still consume goods that they otherwise are not as efficient at producing or unable to produce within their borders. The ability to still purchase tropical fruit in the middle of winter within a country located far from the equator is due to trade. Comparative advantage is not a novice idea or concept. There has been much research and analysis done on comparative advantage and the benefits of trade. One benefit from trade is believed to be that trade helps in reducing food insecurity.

Food security is defined by the Food and Agriculture Organization (FAO), as a "state in which all people, at all times, have both physical and economic access with an adequate, safe and nutritious food source, meeting the diet and food tastes, ensuring an active and healthy life" (Ly et al. 2020; FAO Agriculture and Development Economics Division 2006). Food insecurity is the opposite and is quite prevalent throughout the world. In the World Food Programme's (WFP) 2025 Global Outlook, more than 343 million people across 74 countries are acutely food insecure, a 10% increase from last year and just shy of the record reached during the [COIVD-19] pandemic with 1.9 million people on the brink of famine (World Food Programme 2024). Loss and the absence of adequate access to staple foods is often devastating for households [who are food insecure and low-income], leading to periods of severe malnutrition that have both short term and long-term health, productivity, employment, and income consequences for household members (Smith and Glauber 2020). But international trade allows global production activities to take place in the most appropriate areas and for food to move from countries with abundant food sources to countries that do not have enough supplies (Runge 2003). This movement has the potential to decrease food insecurity. However, conflict, economic factors, and climate change remain the main drivers of food insecurity, with 65% of acutely food-insecure people living in

fragile or conflict-affected situations (The World Bank 2024b). Presently, conflict is causing food insecurity in Gaza, Syria, Ukraine, and Yemen. Within Yemen, which is affecting 17.1 million people (World Food Programme 2024). Conflict within and across countries has only increased over time as the world's interdependency and connectedness has grown.

Income and food security go hand in hand. One in four developing economies and more than half of those experiencing fragility and conflict will be poorer by the end of this year [2024] than they were on the eve of the pandemic (The World Bank 2024b). Half of the world's low-income countries are already in or at high risk of debt distress (The World Bank 2024b). It is much more difficult for people to consume food when they are not able to afford it. Some geographic regions make it difficult to grow food and people living there must rely on outside sources of food to eat. Often countries can import food usually at a lower cost than domestically produced food. International markets for staple agricultural commodities, which have become increasingly important as sources of nutrition for both developing and developed countries over the past 60 years, are likely to become even more important in the future (Smith and Glauber 2020). Thus, trade will become increasingly important for food security (Brenton et al. 2022).

Trade can be extremely helpful in growing countries economically and providing citizens with the tools and resources to live well. Agricultural trade plays an essential role in promoting a new wave of economic growth and transregional allocation of arable land and water resources (Wang et al. 2023). The number of products being traded around the globe has also increased in monetary value. Between 1995 and 2020, global trade in agricultural exports increased by $1.1 trillion USD (Food and Agricultural Organization 2022). In 1995 there was over $300 billion USD traded of food and agricultural products (roughly $400 billion USD). In 2020, there was just shy of $1.5 trillion USD of food and agricultural products traded globally (Food and

Agricultural Organization 2022). The growth in agricultural trade volumes reflects long-term population and income trends that have increased per capita consumption of high-value food products (Alexandratos and Bruinsma 2012). As economies continue to grow and society advances, trade can help meet the demands of people for products and services. Trade assists in the facilitation of feeding the world and ensures people have a consistent supply of food.

For the vast majority of countries, food security cannot be guaranteed by domestic production alone (Brenton et al. 2022). Trade is essential for lowering the number of people who are food insecure. Imports can be critical during difficult production time periods for various crops. Exports can be a way for agricultural producers in developing countries to increase returns on their farm while raising their own country's aggregate income (Brenton et al. 2022). In a few countries, exports of raw agricultural commodities total 15-30% of total GDP (Gollin 2010). In 2016, the value of exports and imports accounted for 72% of world agricultural production (Leibovici and Adamopoulos 2024). Through international trade, export revenue for countries can be used to import input products, such as machinery, fertilizers, and pesticides (Ly et al. 2020). With these imports, producers will be able to produce even more agricultural products, which boosts domestic food production. Agricultural exports can provide a major source of income for some of the poorest people around the world (Brenton et al. 2022). Sadly, many agricultural producers are often also some of the world's poorest.

In middle- and low-income countries, agriculture can make up a large portion of the employment force and country's share of GDP. For the world as a whole, about 40% of workers earn their living primarily from agriculture (Gollin 2010). This number may be less today. For the poorest countries in the world, the fraction of workers earning their living from agriculture is much higher. In those countries, classified by the United Nations as least developed, 65% of the

labor force is employed in agriculture (Gollin 2010). However, in 2012, of the world's 7.1 billion people, an estimated 1.3 billion (19%) were directly engaged in farming, but agriculture represented only 2.8% of overall income (World Bank 2012). The number of people who earn their living from agriculture has been declining (Davis et al. 2023). As of 2024, 15.37% of the world population earns their living from agriculture (Davis et al. 2023; World Population Review 2023). Which is lower than the number of people working in agriculture fourteen years ago. This number may continue to decline.

Much of the food produced in low-income countries is consumed domestically. It is also common for households within low-income countries to spend most of their incomes on food. In a number of surveys, food accounts for two thirds, three fourths or even 80% of household expenditure, with higher numbers in rural areas (where farmers reside) than in urban areas (Gollin 2010). That narrative is changing with waves of rural families migrating to urban areas but is still common. In 1950, 30% of the world's population lived in urban areas (Global Migration Data Analysis Centre 2022). There has been a shift of people migrating to urban areas over time. In 2018, 55% of the world's population lived in urban areas (Global Migration Data Analysis Centre 2022). This number is expected to increase with 60% of the world's population expected to live in urban areas in 2030 (Global Migration Data Analysis Centre 2022). Farmers in developed countries often have higher incomes than farmers in developing countries. This is mainly due to farmers in developed countries having more open access to resources, inputs, credit, and both governmental infrastructure and physical infrastructure within the industry. But as per capita income rises in a country, the agricultural share of GDP typically falls (Timmer 2009).

There are some risks and drawbacks to trade. International trade can expose countries to unexpected shocks to trade costs, trade policy, geopolitical conditions, climate change, or production conditions in exporting countries (Leibovici and Adamopoulos 2024). While international trade is generally a temporary solution for decreasing food insecurity, the risks with trading can also threaten countries' food security and their ability to maintain a stable supply of goods across their borders. For example, trade policy can hinder and affect the free flow of trade between countries. Many of these policies favor domestic protections, in attempts to mitigate short run food crises (Smith and Glauber 2020). In general, high tariffs increase prices and reduce access to agricultural products and thus limit the size of the global market for these products and will reduce the incentive to invest in exporting such products (Brenton et al. 2022).

Countries that are dependent upon imports, especially for food, may be concerned about the stability of their source and the risk of unreliability. One of the biggest risks to food security in food-importing countries is the imposition of export restrictions by exporting countries that curtail global supply and increase prices (Brenton et al. 2022; Leibovici and Adamopoulos 2024). On the other hand, free trade policies allow countries to exploit their comparative advantages in economic activity, increasing average per capita incomes, longer term growth rates, and a country's capacity to fund social safety nets for the poor and thus contribute to improving food security (Smith and Glauber 2020). Along with these challenges, sanitary and phytosanitary requirements can be barriers for trade. For smaller countries, it can be more difficult for them to comply with regulations from larger countries (Brenton et al. 2022). Recent events have revealed a critical need to put into place policies that can safeguard and sustain trade flows of agricultural products (Brenton et al. 2022). The COVID-19 pandemic further exacerbated the global problem of food insecurity. Climate change has also not made it easier for

producers, governments, and individuals to tackle food insecurity. Low-income countries are more at risk to face climate change issues and often lack the ability to adapt to climate change versus higher income countries (Brenton et al. 2022). This can be a concern as the resilience of their food supply is threatened.

International trade does reduce food insecurity and malnutrition during periods of domestic shortages by increasing access to food and attenuating price volatility (Brenton et al. 2022). Trade has been deemed a more efficient mechanism for stabilizing prices than domestic holdings of food stocks (Brenton et al. 2022). Instead of flooding the market with stock holdings after an event or attempting to stockpile goods during stable time periods, trade can allow for markets to still naturally and efficiently operate. Trade can help to balance prices by offering the same goods consumers would have received domestically at the world price. Alternatively, trade can offer substitutes for the original goods. Higher prices for staple foods may not have much effect on the food security status of relatively well-off families but can lead to persistent intergenerational poverty traps for low-income households (Frankenberg and Thomas 2017). But others within the literature would argue this statement acknowledging that food price volatility is correlated with food insecurity across countries (Leibovici and Adamopoulos 2024). Those authors acknowledge the risk in trade manifests itself in international and domestic food price volatility (Leibovici and Adamopoulos 2024). Global production tends to be less volatile than production at the country level and trade plays an important risk-sharing role in the face of domestic production (Brenton et al. 2022; Anderson, Ivanic and Martin 2013; Wright 2012). Often, countries that are structurally food deficient, such as Japan, rely on trade to satisfy domestic demand (Brenton et al. 2022). Japan (as an example) is unable to fully support its people and economy with domestic agricultural production. The goods and products Japan is

abundantly efficient in producing are not food. Therefore, they can trade with other countries that may be more efficient at producing food than they are in exchange for the products and goods they are efficient at producing, such as electronic devices. For developing countries, a similar circumstance may occur. As a group, developing countries become large net importers of food (Brenton et al. 2022; Leibovici and Adamopoulos 2024).

Another drawback, looking directly at how trade is physically carried out, is delays at borders and ports not only increase trade costs but also cause significant amounts of food to be wasted, contributing to the 1.3 billion tons of food (approximately 30% of global production) that the FAO estimates is lost each year (Brenton et al. 2022). When delays occur it can greatly impact the consumption of perishable goods (often agricultural products) that are traded. Delays and losses of goods are particularly likely to occur in developing countries where cold chain logistic services are not widely available and where poor border infrastructure entails little protection from high temperatures and rain for food products that are in transit or held at the border for inspection (Brenton et al. 2022). However, dealing with potential risks and integrating more profoundly and steadily into the global agricultural economy has become an urgent issue that must be addressed to eliminate hunger and achieve sustainable food development (Wang et al. 2023). To the extent that international trade in agricultural commodities improves food security within a country by mitigating the impacts of volatility in domestic food production and prices and increasing real incomes, the standard conclusion drawn by many economists is the importance of international trade is likely to increase in both the near and more distant future (Smith and Glauber 2020). Part of ensuring that international trade continues well into the future is recognizing the need to diminish supply chain disruptions. When supply chain disruptions occur, maritime chokepoints can become stressed and cause delays in international trade. To

capture and effectively measure the change in food security when maritime chokepoints are stressed, the implementation of the gravity model best serves as the model to use. Many researchers have used the gravity model to assess the impact of distance on trade flows (Leitão 2024; Bergstrand 1985; Bergstrand 1989; Eaton and Kortum 2002; Kabir, Salim and Al-Mawali 2017).

Chapter 3 - Theory behind the Gravity Model

In 1962, Jan Tinberger discovered that the size of bilateral trade flows between any two countries can be approximated by Newtonian "gravity" (Yoto V. Yotov, et al. 2016). Tinberger proposed that trade between country *i* and *j* (where *i* and *j* represent two countries) can be modeled very similar to Newton's law of gravity. Using a measure of a country's income and the distance between the two countries one can build a gravity equation. A proxy for a country's income is usually the GDP (Gross Domestic Product) as their "mass" and the distance between the two countries as their "radius" to represent a gravity equation. The GDP of each country is multiplied and divided by the distance between them and multiplied by a constant. For comparison:

$$F = G\frac{(m_1 m_2)}{r^2} \qquad X_{ij} = \lambda\frac{(GDP_i)^{\alpha}(GDP_j)^{\beta}}{dist_{ij}^{\gamma}}$$

Newton's Law of Gravity Tinberger's Gravity Model

Many researchers have previously used the gravity model to assess the impact of distance on trade flows (Márquez-Ramos and Martínez-Zarzoso 2008; Wu et al. 2020). Often, they use the gravity model to isolate various variables of particular importance. Distance is included in these analyses but may or may not be the variable of focus. For example, recently there has been work done on investigating how distance affects the boost to trade from regional trade agreements (RTA) (Baier, Bergstrand and Clance 2018; Freeman and Pienknagura 2019; Vicard 2011; Freeman and Lewis 2021). They evaluate the distance variable and its relationship with RTAs, but distance is not the only variable or component of importance. This paper differs from those works because it uses an alternative method for calculating distances between two countries and is the main variable of evaluation.

Based on previous estimations and work done with gravity models, there are five arguments that make the gravity model successful and popular amongst experts (Yoto V. Yotov, et al. 2016; Corrêa 2021). Within Yotov et al. 2016 paper, the authors' first argument is that the gravity model is very intuitive. The model uses the metaphor from Newton's law of gravity to predict international trade between two countries. Their second argument is that it is a structural model with strong theoretical foundations. This attribute makes the model a popular tool for counterfactual analysis such as quantifying the effects of trade policy. Third, it represents a realistic equilibrium environment that can simultaneously accommodate multiple countries, sectors, and firms. This allows the model to capture the possibility that sectors are linked and if policy in one sector changes, it can trigger ripple effects to occur in other sectors. In this study only the agricultural sector is considered, but the gravity model has the potential to evaluate multiple sectors or industries. Fourth, it is a very flexible structure that can be integrated within broader models to study links between other notable factors of a country's economy. Such as, investments, labor markets, and the environment. Lastly, one of the most attractive properties of the gravity model is its ability to predict bilateral trade flows. Gravity equations consistently deliver a close fit (explain 60-90%) of the variance with aggregated data as well as with and sectoral bilateral trade flows data for goods and services (Head and Mayer 2014). The gravity model is widely used to study the effects of bilateral trade costs on bilateral trade flows due to modest data requirements and strong microeconomic foundations.

Enforcing log-linearization within the model allows the gravity equation to take on a linear function and therefore, is easier to estimate using ordinary least squares (OLS). One drawback to this is that the model does not consider countries with zero trade flows (Yoto V. Yotov, et al. 2016). Observations with zero trade flows will be dropped from the model and

excluded. This can be an issue for disaggregated data (not the case here). The data used in this study will be aggregated for each country. The benefit to using OLS is that estimates are consistent, unbiased, and efficient if the standard errors are homoscedastic, there is orthogonality between the errors, and none of the explanatory variables are a linear combination of other explanatory variables (Kravchenko and Doytchinova 2020).

The gravity equation will then become (with OLS):

$$\ln(X_{ijt}) = \ln(\lambda) + \alpha \ln(GDP_{it}) + \beta \ln(GDP_{jt}) - \gamma(dist_{ij}) + \varepsilon_{ijt}$$

Where *i* and *j* are the origin and destination countries, and *t* represents time (year). *X* represents the value of exports from countries *i* (the exporter) and *j* (the importer). *GDP* is the respective country's Gross Domestic Product. *Dist* is the bilateral distance between the two countries. A model with only data relating to a country's size (GDP) is considered to be a naive gravity model. Not including other factors that influence trade will not produce an accurate estimation of the true trade value between countries. There are several factors that influence trade besides the economic size of a country. (Herman 2023) recognizes one of the primary challenges of the empirical model is finding appropriate proxy variables to adequately capture all important types of trade costs. Cultural affinities, geography, multinational corporations, and shared borders (Yoto V. Yotov, et al. 2016; Herman 2023) particularly contribute to endorsing or hindering trade between two countries. Trade policy (tariffs and other trade barriers) and agreements between countries also contribute to how much trade occurs between countries.

To include other factors that influence trade within the gravity model, an accepted practice is to use fixed effects within the model to maintain accurate estimations (Redding and Venables, 2004 and Head and Mayer, 2011). Implementing fixed effects does present challenges but it controls observable and unobservable multilateral characteristics that vary over time for

each importing and exporting country. Drawbacks to using fixed effects within a model will affect the econometric analysis particularly in the possibility of creating biases and inconsistencies.

There are many challenges to estimating gravity models. There are multilateral resistances that are not always observable to the researcher (or policy maker) (Trefler 1993). If bilateral trade costs are not properly specified it can be difficult to know whether the model is producing accurate results. Other challenges present are heteroscedasticity and endogeneity of trade policy (Trefler 1993). It is well known that heteroscedasticity is likely to be present in trade data (Yoto V. Yotov, et al. 2016). When heteroscedasticity is present, the estimates can be biased and inconsistent in a log-linear form with the OLS estimator. A model with endogeneity could be due to trade policy that may be correlated with unobservable cross-sectional trade costs (Yoto V. Yotov, et al. 2016). A country is more likely to trade with another country that they are already very significant trading partners with. The United States, Mexico, and Canada have had a long-time trading partnership with one another and are likely to continue to increase trade between one another. Other countries with similar partnerships will also continue to foster trading relations amongst themselves.

For further analysis, the model used in this study could be altered to address these many challenges and issues within the data mentioned above. But for the sake of simplicity and time, fixed effects will be enforced, and the trade values of each country will be aggregated. This will help to eliminate some of these issues raised previously, but it will not solve all of them. There may be endogeneity and heteroscedasticity present within the study data and model at this initial stage. Main recommendations for robust, consistent and unbiased analysis of gravity models are to include intranational trade data, add to the gravity equation directional fixed effects of

temporal variation (country-year or country-sector-year), impose country pair fixed effects, and use the Poisson Pseudo Maximum Likelihood (PPML) estimator (Corrêa 2021).

Chapter 4 - Methods and Data

This thesis assesses the effects of chokepoint disruptions using a gravity trade model. The analysis uses bilateral imports of maize, wheat, and rice, in quantities, converted to calories using the conversion factors from FAO Food Balance Sheets Handbook Annex I (Food and Agricultural Organization 2001). The bilateral trade flows come from the Detailed Trade Matrix dataset from FAOSTAT (FAOSTAT 2024). Dyadic characteristics (such as a country's participation in trade agreements, shared languages between trading partners, and if countries share borders, etc.) are from the United States International Trade Commission (USITC) Dynamic Gravity Portal Trade and Production Database (Gurevich and Herman 2018) and the CEPII Gravity Database (Conte, Cotterlaz and Mayer 2022; Conte, Cotterlaz and Mayer 2023). This study also uses the World Port Index (WPI) from the U.S. National Geospatial-Intelligence Agency (U.S. National Geospatial-Intelligence Agency 2019) to construct a distance database containing maritime distances with and without the Panama Canal, the Suez Canal, or the Malacca Strait in shipping trade routes. Using actual trade routes overseas has not previously been used in gravity models. Most databases used for gravity analysis have distance data between two countries, but the distances are a measurement from the most populated city, the capital city in each country (Conte et al. 2023), or weighted distances that use city-level data to account for the geographic distribution of population within each country (Gurevich et al. 2018; Conte et al. 2023; Mayer and Zignago 2005).

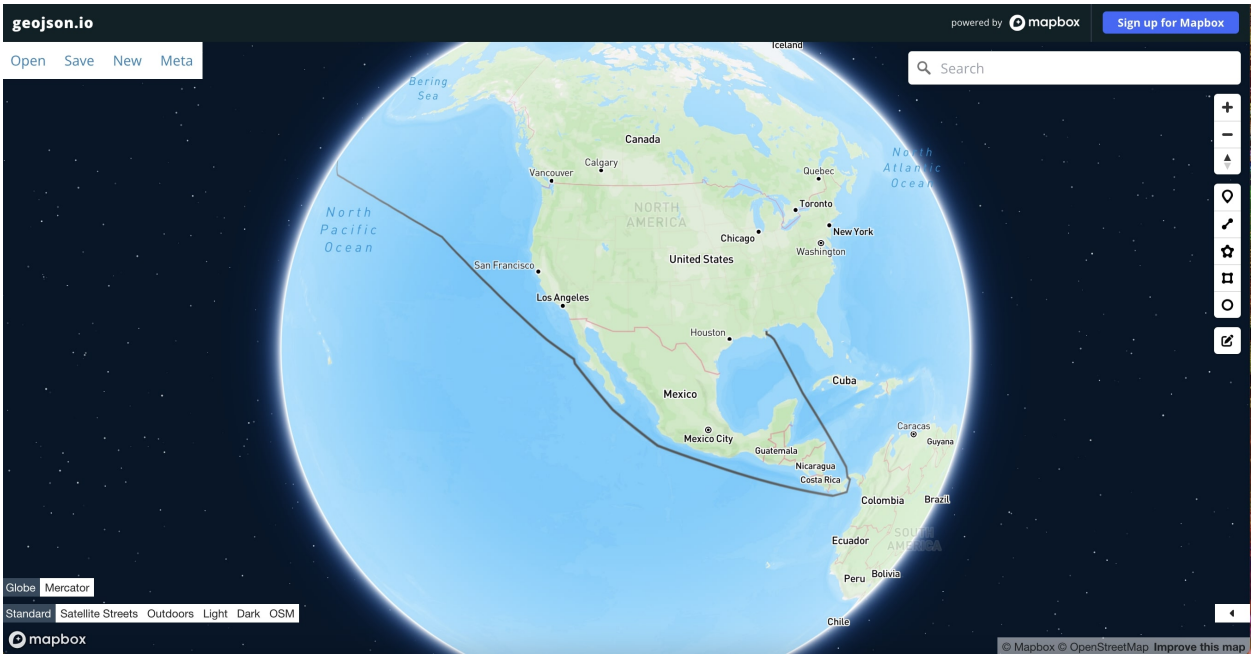
For the construction of the distance database in this analysis the selection of the largest port of each country that borders an ocean, or sea is required (using the WPI dataset). The WPI dataset contains every port in the world and characteristics about each port (including port size and port coordinates). Some countries have borders on more than one ocean or sea. For most

countries in this select group, there is the inclusion of two ports per country, one on each ocean or sea of their border (see Appendix Table A.1 for this group and Appendix Table A.2, A.3, A.4, A.5 for notes on decisions of ports for these countries and tables with corresponding port size and countries). The selection of each port was based on various sources and data that revealed either the physical size of the port, the volume of cargo that passed through the port, or information on which ports handle the most agricultural goods exported or imported from it. For example, the port of New Orleans in the United States is not the largest port within this country. The port of Los Angeles or the port of New York-New Jersey is the largest port in terms of size (U.S. National Geospatial-Intelligence Agency 2019) and volume of cargo (World Shipping Council 2023). In 2023, the port of Los Angeles handled 8.63 million TEUs (World Shipping Council 2023) and had a total of 178.6 million metric revenue tons (Port of Los Angeles 2024) . In the same year, the port of New York-New Jersey handled 7.81 million TEUs (World Shipping Council 2023) and 136,575,034 tons (Clevenger 2021). Both of these ports are listed within the top 25 of the biggest container ports in the world (World Shipping Council 2023). However, the Gulf Coast and the Pacific Northwest regions are two regions that see the most volume of agricultural products exiting the United States (Sytsma and Wilson 2020). The port of Los Angeles sees a high volume of imports arriving to the United States (The Port of Los Angeles 2024). The Mississippi Gulf exports about 2 billion bushels of grain each year (United States Department of Agriculture: Agriculture Marketing Service 2017). This includes the port of New Orleans. In 2017, about 47% of United States agricultural exports left from the port of New Orleans (United States Department of Agriculture: Agriculture Marketing Service 2017) and more than 92,208,560 tons of freight volume traveled passed through this port in 2021

(Clevenger 2021). Due to these facts, the port of New Orleans is the only port selected for the United States.

In total, there are 198 ports that are used to calculate distances between 140 countries (based on the number of countries that data could be pulled from both the port and trade data). Using the coordinates as inputs in the maritime route tool, Searoute, developed by (Gaffuri 2024), the algorithm computes the shortest maritime route following the path of the most used shipping routes published in the Oak Ridge National Labs' Global Shipping Lane Network (2000). Gaffuri's algorithm also allows closing maritime chokepoints to obtain alternative shortest paths along actual shipping routes. For example, the distance between the port of New Orleans in the United States and the port of Shanghai in China (going through the Panama Canal) is 18,898.44 miles. A closure of the Panama Canal forces trade between the U.S. and China to go through the Atlantic Ocean, adding 6,603.44 more miles to the trip. Using this software provides the ability to determine counterfactual changes in bilateral distance for the entire set of potential partners of 140 countries. See the figures below for the example route between the United States and China.

Figure 4.1 Shortest maritime route from New Orleans, USA to Shanghai, CHN (1)

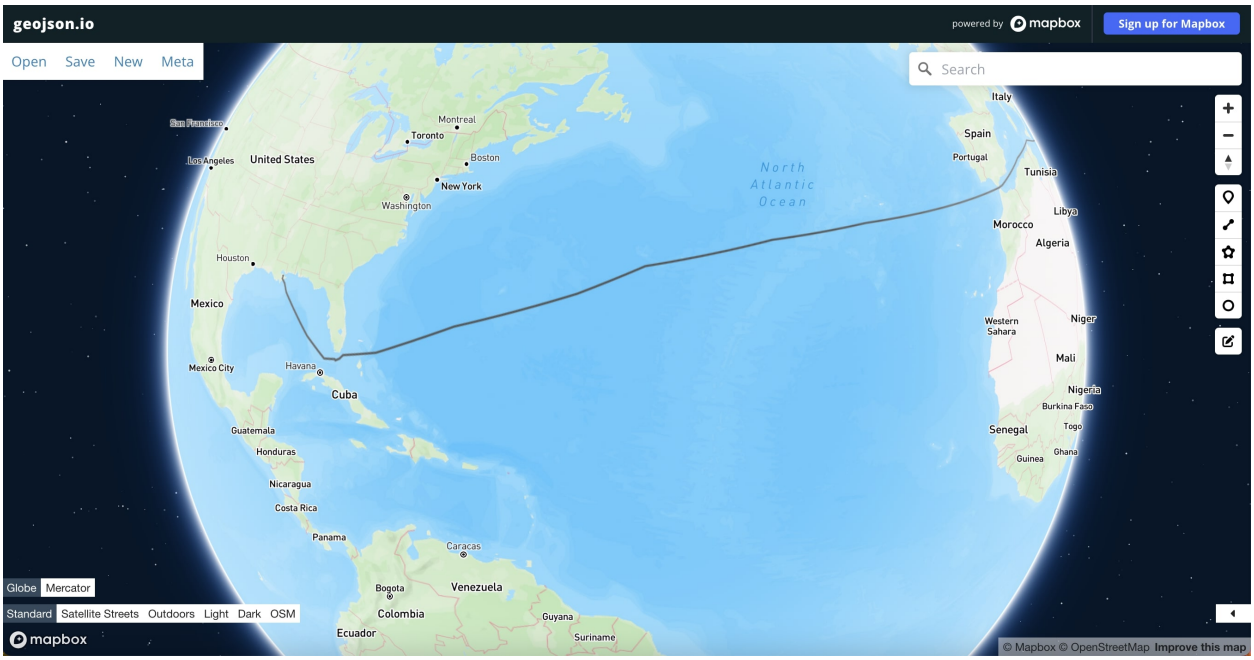


Source: Searoute software by J. Gaffuri, 2024 using WPI data.

Figure 4.2 Shortest maritime route from New Orleans, USA to Shanghai, CHN (2)

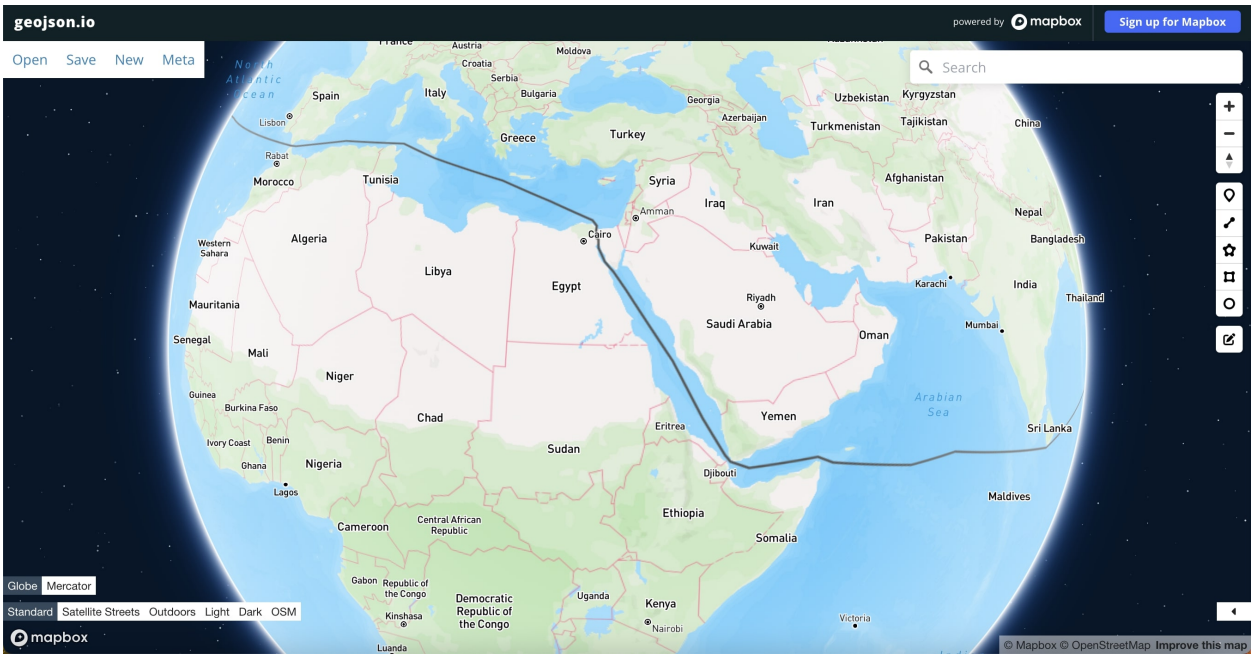
Source: Searoute software by J. Gaffuri, 2024 using WPI data.

Figure 4.3 Maritime route from New Orleans, USA to Shanghai, CHN with exclusion of the Panama Canal (1)



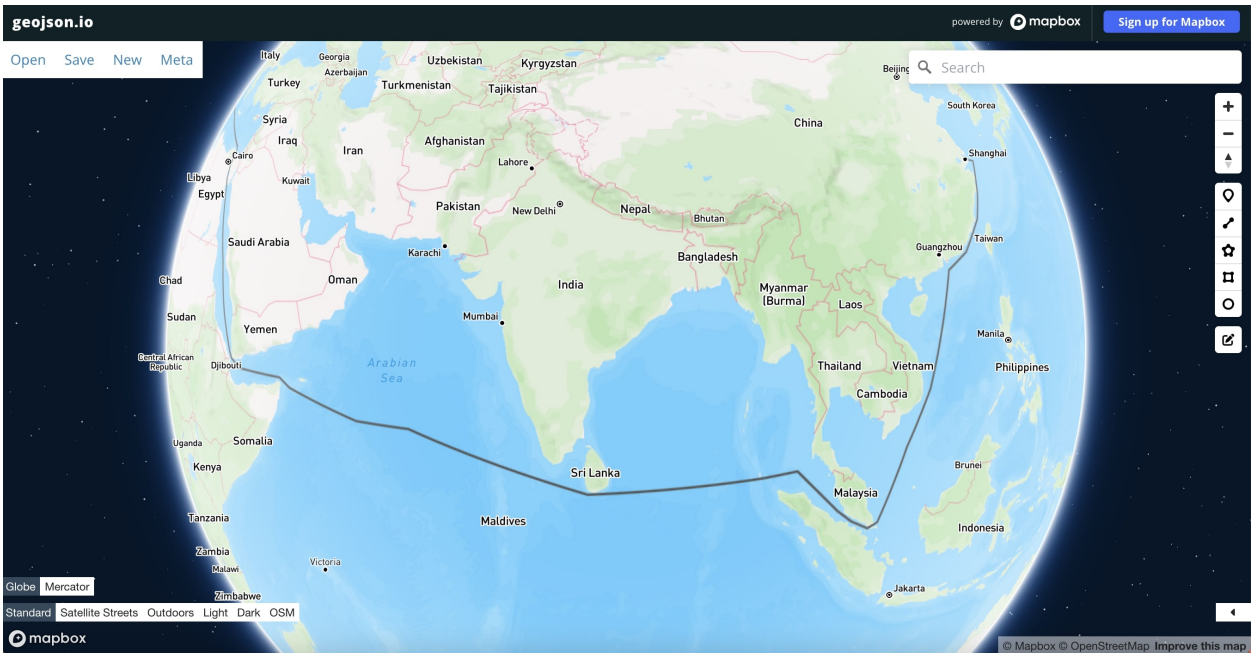
Source: Searoute software by J. Gaffuri, 2024 using WPI data.

Figure 4.4 Maritime route from New Orleans, USA to Shanghai, CHN with exclusion of the Panama Canal (2)



Source: Searoute software by J. Gaffuri, 2024 using WPI data.

Figure 4.5 Maritime route from New Orleans, USA to Shanghai, CHN with exclusion of the Panama Canal (3)



Source: Searoute software by J. Gaffuri, 2024 using WPI data.

Using the distances calculated from Searoute, trade data from FAOSTAT, and country characteristics from USITC Gravity Portal's Dynamic Gravity Dataset (DGD) and CEPII gravity dataset, the following fixed effects gravity equation (with OLS) can be constructed to elicit country-by-country changes in imported calories:

$$\log(C_{ijt}) = \mu_t + \mu_i + \mu_j + \beta_4 \log(distKM_{ij}) + \beta_5 contig_{ij} + \beta_6 fta\_WTO_{ijt} + \beta_7 commlang\_off_{ij} + \beta_8 member\_joint\_WTO_{ijt} + \beta_9 member\_EU\_joint_{ijt} + \varepsilon_{ijt}$$

where *i* represents the origin or exporting country (partner country) and *j* represents the destination or importing country (reporter country), and *t* represents time (year). *C* represents the calories traded from *i* (exporter) to *j* (importer). The variables μ_i and μ_j represent the fixed effect variables controlling for individual country changes. μ_i is the exporting country in the trading country pair and μ_j is the importing country within the trading country pair. The variable μ_t is

imposing fixed effects for year. This controls for major changes from year to year within the years evaluated. The variable $distKM_{ij}$ is the bilateral distance between two countries (the distance between their two ports from the created distance database) and is logged so that it can be interpreted as an elasticity (in percentage terms) instead of absolute change. To capture other factors that influence trade the inclusion of the binary variables: $contig_{ij}$ (also known as contiguity is the shared border between *i* and *j*), participation in a Free Trade Agreement (of either *i* or *j*) is fta_wto_{ijt}, shared common language (between *i* and *j*) is $commlang\_off_{ij}$, joint members of the World Trade Organization (WTO) is $member\_wto\_joint_{ijt}$, and joint members of the European Union (EU)[1] is $member\_eu\_joint_{ijt}$. Contiguity will capture geographic features of the countries trading and common language will capture cultural affinities. Countries jointly belonging to a trade organization (WTO or EU) will represent countries' involvement in trade policy (Gurevich and Herman 2018; United States International Trade Commission 2021) as well as if a country participates in a free trade agreement (FTA). This is the only representation of trade policy used within this specific model for this study and even though there is typically a lag in trade policy between countries, that will not be accounted for within the model.

The public datasets that the binary variables are pulled from have limited data for the years evaluated within this analysis. The CEPII has a more complete dataset ranging from 1948-2021 (Conte et al. 2022; Conte et al. 2023). For contiguity, common languages, and free trade agreements of country pairs in the year 2022, the most recent year's data was used (2021 values were applied to 2022). CEPII has data on individual countries' participation in the WTO or EU

[1] Contiguity, common languages, and free trade agreement participation binary variables come from the CEPII dataset (2010-2021) and joint membership for the WTO or EU comes from the USITC Dynamic Gravity Dataset (2010-2019).

but does not have the joint membership of country pairs. However, the USITC dataset has data from 1948-2019 for joint membership of country pairs for the WTO or EU. For the years 2020, 2021, and 2022, the most recent year's data was used to include these two binary variables.

Not every country trades with one another. There are some countries that do not trade in agricultural products and others that do not maintain good relations. For whatever reason that some country pairs may not trade with one another, their calorie value is zero. For the initial evaluation of this model, observations of imported calories greater than zero will only be evaluated. There are five countries that do not export maize, rice, or wheat to other countries. These countries are Comoros (COM), Cabo Verde (CPV), Faroe Islands (FRO), the Solomon Islands (SLB), and Samoa (WSM). This group only imports grains from various sources but has zero exports (in these grains) to other countries. The inclusion of only imported calories greater than zero will focus on the demand side of grains within this paper. Intranational trade is not initially included. The inclusion of the zero trade values would shift the focus on the supply side. To include zero trade values between country pairs, the imposition of Poisson Pseudo Maximum Likelihood (PPML) would correct this issue of exclusion. PPML also assists with heteroscedasticity, fixed effects, and simple interpretation (Yoto V. Yotov, et al. 2016).

Imposing fixed effects will correct for effects that are specific to that trading country pair (Yoto V. Yotov, et al. 2016; Francois, Leister and Rojas-Romagosa 2015) and is a widely common practice for conducting gravity models, as seen in the previous section. Effects that are specific to a trading country pair could be: common colonizer, common religions between countries, both country's economy size (usually Gross Domestic Product or another income factor), population size of both countries, and many others (Herman 2023; Bacchetta et al. 2012). For example, the dummy coefficient on an exporting country will show the difference in

magnitude that country's exports are relative to the base country that is left out (in this case Angola). If country-pair fixed effects are imposed on a gravity model, the model loses the ability to include the distance variable.

Interpreting the coefficient of the country coefficients will be the variables that capture all country-specific characteristics and will control for a country's overall level of imports or exports (Bacchetta et al. 2012). For example, if the country variable holds a value of one then United States (or any other country) is the exporting country and zero otherwise. The importer variable will be one in cases when the importing country is United States (or any other country) and zero otherwise. This is true for all other countries. Conducting the model this way will lose data consisting of sectoral importance (specifically in tariff and other trade policies), which will eliminate some of the "characteristic" variables in a standard gravity trade model. With fixed effects in place, trade policies will simply be absorbed into the model; that are not specifically built into the model as variables already. The model will no longer estimate the impact of any variable affecting exporters' propensity to export to all destinations, affecting imports without regard to origin, as well as, representing some summary statistics of country-specific variables (Head and Mayer 2014). The focus of this model will be on the distance between importing and exporting countries and less on the trade policies between them. Trade policy is a crucial factor to the amount of goods traded between countries, but this study is attempting to evaluate the importance of maritime passageways on trade and less on the impact of trade policy between countries.

This study specifically evaluates the agricultural trade sector in three staple food crops: maize, wheat, and rice. Many countries, both developed and developing, consume large quantities of these grains. The analysis compares expected imported calories which are

calculated from the regression model and compared against the expected imported calories under the counterfactual scenario with the alternative distance. The trade values of the three grains are aggregated for each country and not evaluated on an individual product scale. Aggregating the grains allows for a more holistic measure of food security and captures the shift in preferences due to price. If the price of wheat increases, consumers may buy less bread or pasta and start purchasing rice as a substitute good.

For further development of this model, the inclusion of other industries and sectors could help show which sector or industry is most dependent on the Panama Canal, the Suez Canal, or the Malacca Strait. Half of seaborne trade and 45% of the total world fleet are main transportation modes for commodities such as grain, ore, and coal (Brancaccio et al. 2020). There could be speculation on which industries would be most dependent on one of these passageways based on geography, but it may not be definitive or proven. For example, the Middle East produces large quantities of oil. The Suez Canal is in the Middle East so one would assume that oil would be a high traffic item passing through the canal.

Within this study, bilateral trade costs are assumed to be iceberg costs (standard with literature in Samuelson 1952 and Yoto V. Yotov, et al. 2016). This means that prices are fixed and do not change. However, this is not typically the case within industry. Cargo ships may be at full capacity of goods in one direction to a country and empty (or less than full capacity) on the way back to the origin country. Because the complete journey consists of different capacity amounts, it is more expensive to send ships back that are not at the same or full capacity as when the ship started its journey. Shipments one-way on a complete journey can be more expensive even though the ships travel the same exact kilometers and use the same amount of fuel. Shipping contracts and costs fluctuate and differ depending on the country of origin and country

of destination, making prices volatile and dynamic (Besley et al. 2015; Brancaccio et al. 2020). Transport companies influence the transportation costs of goods as a result and therefore influence global imports and exports (Brancaccio et al. 2020). The author also notes that there is an imbalance between countries that trade in commodities; a country is either a large net exporter or a larger net importer. In the past, it has been a widely accepted practice to assume iceberg costs for transportation within gravity models. Recently, gravity trade model literature is starting to explore and incorporate dynamic pricing within models instead of relying on the assumption that bilateral trade costs are stagnant (Francois et al. 2015). For further model development, the incorporation of dynamic pricing would add significant value. Since prices are kept fixed, the effects determined from this analysis are short-term impacts. Capturing only short-run effects does not allow countries to adjust to a disruption and change the origin of their imports amongst their trading partners that would occur in a long-run analysis.

To run the gravity trade model, the statistical software R conducts a regression and calculates the predicted and exponential caloric values using regression coefficients for the counterfactual scenarios. The comparisons of calories traded for every country pair under different distance scenarios will emphasize which countries are most dependent on the Suez Canal, the Panama Canal, and the Malacca strait. Under the baseline scenario, there are no restrictions on the type of route traveled between two countries. It is the shortest minimum distance between them. For the three counterfactual scenarios, country pairs are required to take the next shortest route between them without using one of the three passageways highlighted in this paper. For country pairs that are forced to take the next possible shortest route in the counterfactuals, there is an expectation of a decrease in calories traded between them. The author expects countries in Europe, Asia, Africa, and the Middle East to be most dependent on the Suez

Canal, Panama Canal, or Malacca Strait when trading. One may expect countries in North America and South America to experience no caloric change or very little caloric change based on the number of countries located within these regions that have access to two oceans. The objective of this research is not to predict the effects of a specific passageway closure but to help in understanding the heterogeneity in geographic patterns and the impacts of maritime passageway closures.

The distance ($distKM_{ij}$) coefficient should be negative because the further apart two countries are from one another, the more costly and difficult it is to trade with one another. For the coefficients on contiguity, common language, joint members of the EU or WTO, and free trade agreements the expectation for these values is to be positive because these factors are all expected to increase trade between two countries.

The imposition of fixed effects controls for all external changes that are specific to a country outside of the variables or trade factors that have been accounted for within the gravity equation. For example, the imposition of fixed effects captures a country's gross domestic product (GDP) and other income variables of a country. There are other year-to-year changes or country specific changes over the course of the dataset that will be accounted for through fixed effects.

Chapter 5 - Results

See Table 5.1 for comparison of regression models with different variables. As shown in the table, omitted variable bias decreases with the addition of variables influencing trade. Starting with an equation consisting of only the distance between countries yields a large coefficient on the distance variable. As other variables are added to the equation, the distance coefficient decreases in absolute value reducing omitted variable bias..

Table 5.1 Gravity Model Regression(s) with added variables

Table 5.1 Regression Comparison

	Dependent variable:			
	log(Total Import Qty Calories)			
	Dist. Only	Cont. added	FTA added	All others
	(1)	(2)	(3)	(4)
$\log(distKM_{ij})$	-1.754***	-1.564***	-1.398***	-1.194***
	(0.025)	(0.028)	(0.030)	(0.031)
$contig_{ij}$		1.552***	1.469***	1.508***
		(0.092)	(0.092)	(0.091)
fta_wto_{ij}			0.893***	0.709***
			(0.062)	(0.062)
$comlang\_off_{ij}$				0.412***
				(0.066)
$member\_wto\_joint_{ij}$				0.807***
				(0.252)
$member\_eu\_joint_{ij}$				2.580***
				(0.107)
FE exporter μ_i	Yes	Yes	Yes	Yes
FE importer μ_j	Yes	Yes	Yes	Yes
FE year μ_t	Yes	Yes	Yes	Yes
Constant	38.596***	36.058***	34.390***	32.124***
	(0.895)	(0.903)	(0.907)	(0.932)
Observations	28,235	28,235	28,235	28,235
R^2	0.554	0.559	0.562	0.571
Adjusted R^2	0.550	0.554	0.557	0.567

Residual Std. Error	3.424	3.407	3.394	3.357
F Statistic	121.456***	123.261***	124.466***	128.036***

Note: *p<0.1; **p<0.05; ***p<0.01

To complete the analysis and find the effect on food security through changes in imported calories, due to additional distance on maritime trade routes, the predicted values of imported calories from the regression can be calculated first. These predicted values use the distances calculated from Searoute under simulations without the use of a maritime passageway but with the same regression model. By doing this, one can see how changes in the dependent variables of the regression affect the total imported calories according to this model. However, the predicted values are still in the log scale so taking the exponentials of these predicted values returns them to total calories imported. Summing the exponentials and grouping by the importers yields the total calories imported for each country. Based on these numbers, one can calculate the total percentage change in calories by taking the sum of the exponentials (for each country under a different counterfactual scenario) minus the total imported calories (for the same country but with the original predicted calorie values) divided by the original predicted imported calories multiplied by one hundred. If this returns a negative value, this means that the prediction without the maritime passage is lower than the initial prediction of calories with the passageway. This represents a decrease in imported calories. For example, when the Panama Canal is not a part of the maritime trade route, total counterfactual predicted imported calories for El Salvador is 1,370 trillion. However, when the Panama Canal is included in the maritime trade routes, total expected imported calories for El Salvador is 3,620 trillion under normal maritime trade routes. Following the steps above, the total percentage change is then a 62.00% decline in imported calories for El Salvador. Demonstrating this change in percentage terms is easier to comprehend than to visualize the change in millions of calories.

The specification in the 'All Others' regression model in Table 5.1 reveals that the distance between ports, contiguity, common language, participation in an FTA, or countries being joint members of the WTO or EU explains 57% of the variance in bilateral trade flows of imported calories. As shown in the table, omitted variable bias decreases with the addition of variables influencing trade. Starting with an equation consisting of only the distance between countries yields a large coefficient on the distance variable. As other variables are added to the equation, the distance coefficient decreases to –1.19. For a 1% increase in the distance between a trading country pair (one way), there is a 1.19% decrease in the number of imported calories between the pair. This estimate is higher than distance coefficients in previous gravity literature evaluating solely agricultural products but is closer to total trade estimates (Grant and Boys 2012). Other literature has found the distance coefficient to be on average around -0.93 (Head and Mayer 2014). But still others have found in a fixed effects OLS gravity analysis to have a distance coefficient of -1.216 (Yoto V. Yotov, et al. 2016) which is close to the coefficient in this analysis.

The other variable coefficient estimates differ from prior literature estimates. Contiguity coefficients on average range from 0.53 to 0.65 and common language coefficients range on average from 0.39 to 0.54 (Head and Mayer 2014) but in other sources contiguity coefficients can be as low as 0.22 and as high as 0.61 for common language coefficients specifically for OLS analyses (Yoto V. Yotov, et al. 2016). This analysis coefficient on common language follows prior literature but for contiguity has a higher estimate on the coefficient. Looking at a gravity analysis evaluating only agricultural products, the coefficient on contiguity is around 0.77 and around 0.51 for shared common language between a trading pair (Grant and Boys 2012). For joint membership of the EU, previous estimates for the coefficient, on average ranges from 0.14

to 0.5 (Head and Mayer 2014). Within this study, the estimate for the joint membership of the EU is much greater than these prior estimations.

To determine the percentage change in the dependent variable (imported calories) from the binary variables, the percentages can be calculated by taking the exponential of the variable coefficient, subtracting one, and multiplying this number by 100. The gravity model is log linearized and requires this method for finding the percentage changes for the dependent variable. For a reporter (importer) country sharing a border with their partner (exporter) country the coefficient on the variable contiguity is 1.508 resulting in the calories traded between the pair that share a border to increase by 351.77%, relative to partners that do not share borders. Country pairs that both participate in a free trade agreement (FTA) have a coefficient of 0.709, therefore the calories traded between them then increase 103.20% due to joint participation in an FTA, relative to country pairs that do not belong on the same FTA. These numbers reflect the importance of sharing a border and participating in a free trade agreement on overall trade between countries. Islands or other isolated countries will face a larger impact on the number of calories traded due to no shared borders. They may need to rely more on FTAs or other trade boosting policies to attempt to make up for being unable to share borders with other countries. Countries trading with one another and sharing the same official language have a coefficient of 0.412 and therefore reflect a 50.98% increase in trade calories between them when a common language is present. It makes sense that countries that speak the same language have a large impact on the amount of calories trade between them (Fidrmuc and Fidrmuc 2016; Frankel and Rose 1998; Melitz and Toubal 2014). Similarities between countries and trade partners will boost trade relations. For country pairs that are both members of the WTO or the EU, the coefficients are 0.807 and 2.580. For country pairs that are both members of the WTO there is a 124.11%

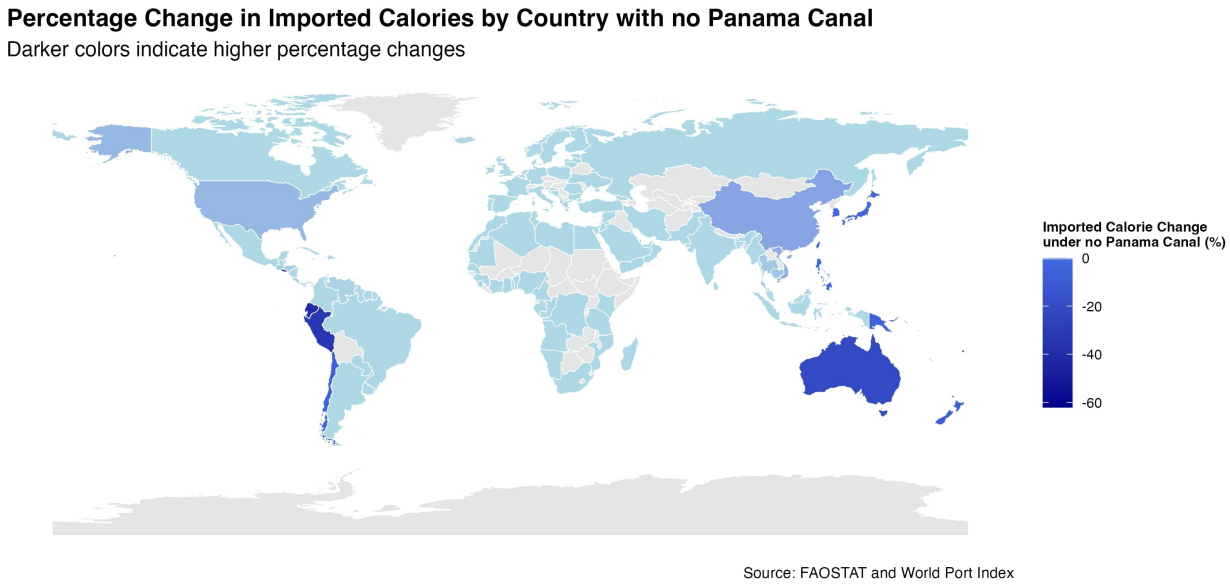
increase in calories trade between them. This is a high percentage change in calories traded between countries. However, this is expected. Countries belonging to a trade organization are thought to be less restrictive and more progressive in their trade policies, at least to their partners. Around 1998, one hundred of 132 (at the time) or 76% of all WTO members were participants in one or more notified regional trade agreement (Goldberg 2016). If participation in both notified and non-notified agreements is taken into account, then the share of participating WTO members rises to 97% (Crawford and Laird 2000). Many of these agreements are inter-linked. When both countries are members of the EU there is a 1219.71% increase in calories traded between the pair. This is the highest percentage change in imported calories from a binary variable. This does make some sense as most, if not all, of the countries belonging to the EU share borders and a common language (amongst many other things) with one another. This is mainly due to the European Union being a "single market" which eliminates trade barriers between the member states creating free movement of goods (European Union 2024; CES at University of North Carolina 2024). It is much easier and cheaper for businesses to trade within the EU than to trade outside of the EU (CES at University of North Carolina 2024). The sharing of a common currency may also be a reason this variable's coefficient is so high. All the variables are statistically significant. The regression results follow expectations for the signs on the coefficients. The magnitude of change in imported calories follows expectations but it is still surprising to see that when both countries are members of the EU, this results in the most increase in imported calories.

Counterfactual Results

The top five countries that experience the most caloric change under the counterfactual scenario where the Panama Canal is no longer available for use on maritime trade routes are El

Salvador (SLV), Ecuador (ECU), Peru (PER), Samoa (WSM), and French Polynesia (PYF). El Salvador displays the largest percentage change in imported calories with a decrease of 62.00%. Ecuador follows with a 40.31% decrease, and Peru, Samoa, and the French Polynesia follow closely with a 32.80%, 31.64%, and 29.77% decrease in imported calories when the Panama Canal is no longer utilized to create the shortest distance between trading partners. These results make sense as the majority of these countries are geographically located close to the Panama Canal and therefore one would expect them to rely on the canal for aiding in the transportation of goods to and from the countries. Eighty countries have a percentage change in the number of calories imported to them due to taking alternative routes that do not consist of using the Panama Canal for travel. Only 59 countries experience no change in their imported calories and can resume using the shortest travel distance to their partners. See Figure 5.1 for a heat map of countries experiencing the most change (in percentage terms) when the Panama Canal is no longer accessible. The darker colors represent a higher decline of imported calories. The lighter colors represent little to no change in imported calories.

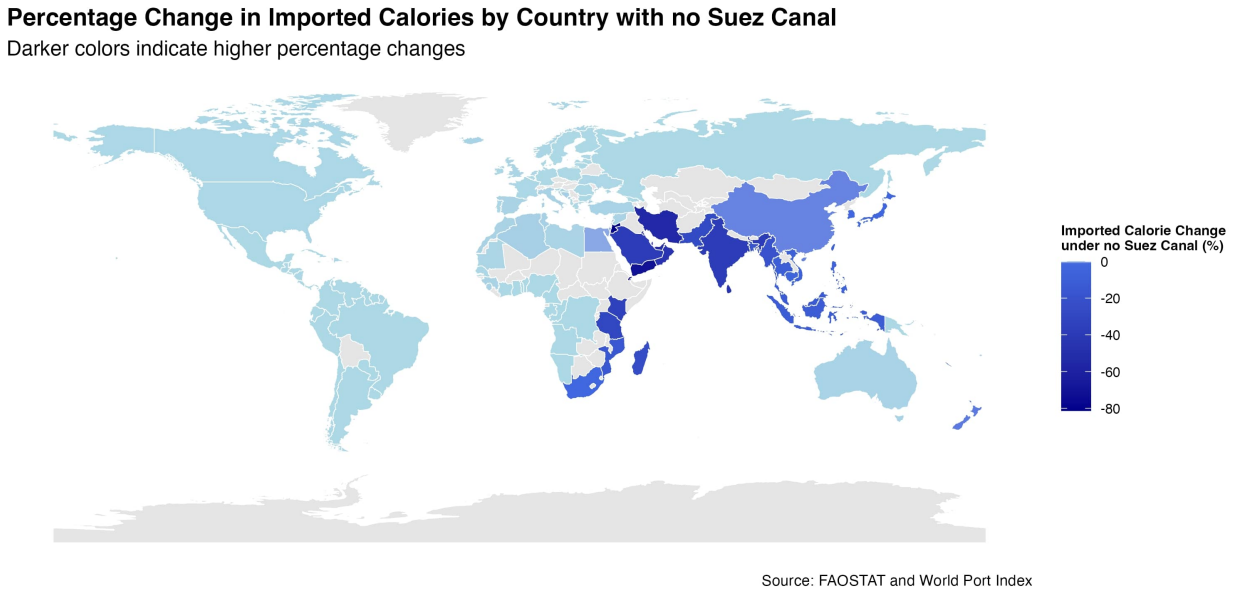
Figure 5.1 Heat map of country caloric percentage changes without the Panama Canal in maritime trade routes



To see the rest of the countries that experience a decrease in imported calories and their respective percentage change, see Table B.1 in (Appendix B).

Countries that experience the most impact from no longer utilizing the Suez Canal on trade routes are Jordan (JOR), Djibouti (DJI), Yemen (YEM), Iran (IRN), and the United Arab Emirates (ARE). Jordan experiences the highest percentage decrease at 81.36%. Djibouti and Yemen follow with a decrease of 75.54% and 70.99% in imported calories. Iran and United Arab Emirates experience a decrease of 54.09% and 50.69% in imported calories. These countries are closely located near the canal and therefore are expected to have greater reliance on the canal on their trade routes. See Figure 5.2 for a heat map of countries experiencing the most change when the Suez Canal is no longer accessible on trade routes.

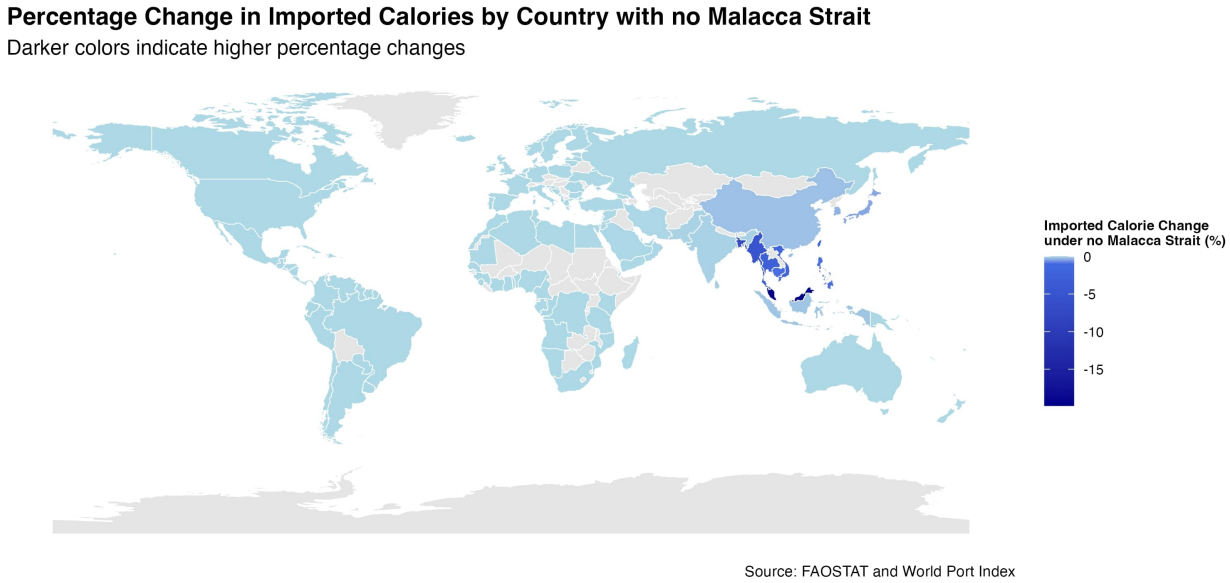
Figure 5.2 Heat map of country caloric percentage change without the Suez Canal in maritime trade routes



For a complete list of countries experiencing a percentage decrease when the Suez Canal is no longer accessible, see Table B.2 (Appendix B).

When the Malacca Strait is no longer accessible for use on maritime trade routes, the top five countries that suffer the most caloric change (in percentage terms) are Malaysia (MYS), Bangladesh (BGD), Myanmar (also known as Burma) (MMR), Singapore (SGP), and Thailand (THA). Malaysia faces the largest decline in imported calories with 19.60%. Bangladesh follows with a 7.03% decrease in imported calories. Myanmar, Singapore, and Thailand experience a decline in imported calories of 5.32%, 3.29%, and 2.47%. These countries all surround the Malacca Strait and logically make sense to be the most dependent on the strait for utilizing transportation routes. Ninety countries experience a percentage change in their imported calories due to the Malacca Strait being unavailable for travel. Only 50 countries are unaffected by this and could remain using their shortest distance trade route to their partners. See Figure 5.3 for a heat map of countries experiencing change in imported calories when the Malacca Strait is no longer accessible.

Figure 5.3 Heat map of country caloric percentage change without the Malacca Strait in maritime trade routes



See Table B.3 (Appendix B) for a table consisting of country rank with the highest to least percentage change under this counterfactual scenario.

Surprisingly, the passageway that experiences the least amount of change in imported calories is the Malacca Strait. One may expect the strait to feed traffic into and out of the Suez Canal and into and out of the Panama Canal. Specifically, it is expected that Asian and Middle Eastern countries would utilize this strait the most. Bailey and Wellesley, 2017 found the Panama Canal and the Malacca Strait to experience the most significant grain throughput due to their positions linking Western and Asian markets. They also note that over one fourth of global soybean exports transit the strait of Malacca, primarily to meet animal feed demand in China and southeast Asia. No longer being able to utilize the Suez Canal on trade routes impacts the most countries and has the highest impact on imported calories. One hundred eleven countries experience a change in their imported calories leaving only 29 countries with no change to their imported calories. Looking at Figure 5.2, there are more dark blue countries for the Suez Canal than the other two counterfactual maps. This result makes sense because looking back to Chapter

1 in Figure 1.2, the Suez Canal experiences the most throughput of grain compared to the other chokepoints.

Differences between a change in expected imported calories over one year compared to over several years may be a result of an increase in trade partnerships and relations amongst countries that are not reliant on one of the three maritime passageways evaluated in this paper. Changes in food security (and trade) may also fluctuate during harsh weather or shortages of maize, wheat, or rice within large producing countries. Food security (and trade) may also decrease for countries during periods of time with mild weather, abundant production, or improvement of technology.

Dramatic changes in trade for a country are smoothed out over time. Evaluating a single year, a country may appear to experience a more severe shock in their trade value (and ultimately, their food security) than when evaluated over the course of twelve years. The model is currently set up to evaluate percentage changes in imported calories across the twelve years included in the dataset. However, various international events occurring in a single year or over the course of three to five years may also have significant influence or impact on a shock to imported calories for a country. For example, the COVID-19 pandemic triggered a fall in world trade in 2020. Global trade is reported to have contracted by 16% in the first two quarters of 2020 (Attinasi et al. 2024). In 2021 and 2022 there was a rapid recovery, with world trade growing by 12.8% and 5.5% and reached pre-pandemic levels by the first quarter of 2021 (Attinasi et al. 2024). There were still some aftershocks from the pandemic that were felt during the second half of 2022 when world trade started to decelerate but has since recovered in 2023 (Attinasi et al. 2024). The COVID-19 pandemic may have impacted countries' imported calories more severely over the course of one year or several years after. As of right now, the current

model used in this analysis is designed to see the impact of short-term effects of these shocks. Most of these major disruptions may only occur for a few days and not over the course of several years. But the ripple effects or changes in trade could persist for a longer period of time as well as how quickly countries may adapt to these shocks. Future analysis of long-term impacts would be of value.

Sensitivity Analysis

Performing a sensitivity analysis will allow for the chance to see if the regression coefficient results are overestimated or underestimated compared to the original regression consisting of the full dataset evaluated. Breaking apart the data range, there are three sensitivity analyses conducted. The first is using data only from the first seven years. For the years 2010-2017, there were not as many major disruptions that affected a widespread number of countries as much as perhaps the last four years of data contained. The second analysis consists of using only data from the even years to create a more random assessment over this specified period of time. The third analysis is to use data solely from the last four years. The third analysis provides an isolated glimpse of how impactful the major disruptions that were mentioned in Chapter 1, were on the relationship between distance and the number of imported calories traded between countries. See below for the full comparison in Table 5.2.

Table 5.2 Sensitivity Analysis

Table 5.2 Sensitivity Analysis

	Dependent variable:			
	log(Total Import Qty Calories)			
	All other variables	Data 2010-2017	Even yrs only	Data 2019-2022
	(1)	(2)	(3)	(4)
$\log(distKM_{ij})$	-1.194***	-1.132***	-1.202***	-1.229***
	(0.031)	(0.039)	(0.042)	(0.054)
$contig_{ij}$	1.508***	1.354***	1.541***	1.858***
	(0.091)	(0.114)	(0.126)	(0.166)
fta_wto_{ij}	0.709***	0.692***	0.738***	0.904***
	(0.062)	(0.082)	(0.085)	(0.108)
$comlang\_off_{ij}$	0.412***	0.383***	0.412***	0.489***
	(0.066)	(0.085)	(0.091)	(0.116)
$member\_wto\_joint_{ij}$	0.807***	0.880***	1.044***	-4.547***
	(0.252)	(0.260)	(0.347)	(1.386)
$member\_eu\_joint_{ij}$	2.580***	2.338***	2.456***	2.894***
	(0.107)	(0.136)	(0.147)	(0.191)
FE exporter μ_i	Yes	Yes	Yes	Yes
FE importer μ_j	Yes	Yes	Yes	Yes
FE year μ_t	Yes	Yes	Yes	Yes
Constant	32.124***	32.850***	31.660***	35.993***
	(0.932)	(1.471)	(1.156)	(1.946)
Observations	28,235	15,889	15,256	9,947
R^2	0.571	0.575	0.568	0.584
Adjusted R^2	0.567	0.567	0.560	0.572
Residual Std. Error	3.357	3.203	3.395	3.504
F Statistic	128.036***	75.080***	69.983***	49.579***
Note:				*p<0.1; **p<0.05; ***p<0.01

Looking at the first sensitivity analysis (model 2 in the table), the distance coefficient is slightly lower than the original model's estimate (model 1 in the table). This would appear to mean that for the data in the years outside of this specific range, the distance estimate is higher

and is slightly overestimating the actual occurrence. The other variable coefficients follow this trend of being lower than the original gravity model estimate.

In the second sensitivity analysis (model 3 in the table), the distance coefficient is higher than the original gravity model estimate. Not by much, but still higher. Most of the other variables are also estimated to be higher than the original model except for the common language variable, which stayed the same, and the joint membership of the EU variable coefficient, which was lower than the original gravity model coefficient. The standard error on these coefficient estimates is also higher than the original gravity model and the first sensitivity standard errors. This could be due to a smaller number of years included in the data compared to the original gravity regression and the first sensitivity analysis.

Evaluating the third sensitivity analysis (model 4 in the table) which consists of the last four years of data, the coefficient estimate on the distance variable has the highest impact on imported calories between two countries compared to the original gravity regression. This is also the case for the other variable coefficient estimates. The variable coefficient on the joint membership of the WTO is negative and of large magnitude. This is surprising in that, if both countries were to belong to a trade organization, the trade value between them should be increasing. However, that may not always be the case. If both countries decide the amount that is traded between is sufficient for both countries for a year or few years, then perhaps a joint membership to the WTO has no impact on the trade between them. Or the countries belonging to the WTO are importing products from countries outside of the WTO through a separate trade agreement. Although the WTO has been historically central and crucial for global trade, there has been recent discussions, that the WTO's ability to be effective in enforcing trade obligations and facilitating negotiations has diminished (Schott and Jung 2019; Payosova, Hufbauer and

Schott 2018). That may be apparent in this sensitivity analysis from the negative coefficient on joint membership to the WTO variable's coefficient estimate. Further work would need to be done to determine the accuracy of that or not.

The three sensitivity analyses do confirm there may be overestimation of the country-by-country declines in imported calories due to overestimation in the original regression coefficients. The third sensitivity analysis consisting of the last four years, has a very similar estimate on the distance coefficient as the original regression coefficient but is slightly higher. The second sensitivity analysis, with even years only, also has a similar coefficient estimate as the original regression and is higher. In 2020, there was the COVID-19 pandemic and in 2022 there was the Russia-Ukraine conflict. Both of those events could be enough reason to pull the distance coefficient estimates higher than years with less disruptive events. Both of those conflicts also persisted longer than a few days, so the impact of the shock lasted longer. The first sensitivity analysis resulted in the smallest distance coefficient which may prove that the most recent years have experienced more severe disruptions and countries have started to use alternative routes. Further analysis and evaluation on using data over a longer period of time would help to confirm the robustness of these results. Although the original gravity model used in this analysis provides a solid foundation for exploring how maritime supply chain disruptions impact food security, there are some limitations and still room for improvement that exist.

Chapter 6 - Limitations and Further Research

The main limitation to this study is that it does not account for countries changing and adapting their trading patterns and partners since this study only captures the short-run effects. For example, when China trades with the United States they utilize the Panama Canal to travel the shortest distance of 18,898.44 miles between Shanghai and New Orleans. Under the counterfactual scenario, without the use of the Panama Canal on maritime trade routes, China is forced to travel 6,603.44 more miles on an alternative route. China could choose to import more grain from countries closer in geography than the United States. China could increase their imports from Australia or another country in South America that does not require access to the Panama Canal. Imports from Brazil to China are not affected without the Panama Canal on a maritime trade route. The distance between Shanghai and Santos is 20,640.22 miles and will not change. This change in trade patterns would be captured under a long-run analysis. A long-run analysis would be beneficial to capture these changes as well as long-lasting impacts of short and long time period trade disruptions.

Another possibility for expanded research is to expand the commodity scope. This study only evaluates three grains and does not include other food sectors and groups. By doing so, the results are only relevant for calorie changes in non-perishable goods (such as grains which can have a long storage life). For perishable products, there would be different distance variables if the products required refrigeration. The inclusion of vegetables or proteins (like meat) has the potential to add value to this model in making it more robust and accurate in addition to better capturing food security. Disaggregating the grains into their own individual analyses may provide some value or benefit but it is difficult to determine that potential benefit as of now. Along these lines, also include separating out how much of these commodities that are traded are

used for human consumption or other uses, such as biofuels or animal consumption would increase the accuracy of these results pertaining to food security. This would need to occur before conducting the analysis, within the data work.

An area of further research within the commodity scope would be to use this model to evaluate the impact of maritime trade disruptions on imported calories but for exporting countries instead of importing countries. For large exporting countries such as Brazil and the United States this analysis may be of interest to see how disruptions may alter their export markets. The geographic regions of where the countries that experience the most severe impact from this occurrence is suspected to look considerably different from the importing countries maps.

Another limitation is that the analysis excludes landlocked countries. There are other agrarian countries that produce grain that are not included in this analysis because they lack direct access to a port. Currently, importing countries that are landlocked, despite efficiently producing the commodities or relying heavily on imports, are excluded from the analysis simply because they are landlocked. To include these countries, distance for them would have to be calculated another way accommodating for the distance traveled over land to a port to then be shipped oversea. Another reason is for some countries, there is port data available but there is no trade data available for them. On the other hand, there can be trade data available for a country but no direct access to a port preventing port data from being available.

With a limited sample size, there could be other ports from countries that handle more agricultural products and would be better options for selection within the port dataset. For example, the author's knowledge and experience for the port selection of the United States, is better than for Colombia or another country with limited knowledge and exposure to their

agricultural systems. New Orleans may not be identified as the largest port in terms of size or total tonnage (Los Angeles or Ports of New Jersey and New York is larger) but selecting New Orleans as the port for the United States is the most logical option because of the volume of agricultural grains travel down the Mississippi River into the Gulf of Mexico and exit the country from there. Another main agricultural hub within the United States is in the Pacific Northwest (Washington) but is not listed as a large port within the WPI dataset. Solely basing port selection on total volume and port size may not correspond to the importance and volume of agricultural goods leaving or entering a port. One may argue another port within (for example) Colombia to be a better option of evaluating than Barranquilla or Buenaventura, the ports that are selected for this analysis. Someone with greater knowledge of the ports and trade flowing in and out of each location may deduce another port to be a better fit for Colombia.

For further research and continuation of this model, the mitigating of limitations in the current model would be ideal. Any data or insight from the transportation sector, although private, would be helpful in adding value to the model. Potentially in the future, taking a closer look into chokepoint dependency on one another would also be intriguing to evaluate. Some of the countries found to have experienced the most change in imported calories may be due to chokepoint dependency. Using the results from this model after addressing the limitations could be very valuable in predicting losses for countries and firms and helpful in knowing which parts of the world would be impacted during supply chain disruptions as they occur.

Chapter 7 - Summary, Implications, and Conclusions

This study set out to answer the question of which countries face the greatest risks to their food supplies when ships can no longer utilize the Panama Canal, the Suez Canal, or the Strait of Malacca due to temporary disruptions. The question is answered using data from FAOSTAT, USITC, CEPII, and the World Port Index. Using counterfactual distances allows for comparison in caloric values of countries under actual trade flows and predicted trade flows.

This study's findings align with and support findings within the Bailey and Wellesley, 2017 paper. That paper identified the top twenty countries that are most exposed to chokepoint disruptions (Table 4 within their paper). Djibouti was the ranked the highest by Bailey and Wellesley with the most exposure to risk. The other top five countries that this paper found to experience the most change in imported calories when the Suez Canal was unusable for a trade route (Jordan, United Arab Emirates, and Yemen) were all within Bailey and Wellesley's list of most exposed chokepoints except for Iran. For the Malacca Strait, Malaysia is on Bailey and Wellesley's list of top twenty most exposed countries. None of the countries listed in this paper's top five countries that experience the most percentage change in imported calories when the Panama Canal is closed, are in Bailey and Wellesley's top twenty list of most chokepoint disruption exposure. There are some similarities and differences between these two works.

Bailey and Wellesley's paper found that low-income food deficit countries are most vulnerable to chokepoint disruptions. However, there are some high-income food deficit countries that also are most exposed to chokepoint disruption (Bailey and Wellesley 2017). To compare and aid in determining the accuracy of this statement, one can compare the Gross Domestic Product of a country with their percentage change in imported calories. Gross Domestic Product (GDP) is a widely used indicator, thought to be a good measure of economic

prosperity of a country (Mumford 2016; The World Bank 2024a). It is the total gross value of all market goods and services produced in a country (Mumford 2016; The World Bank 2024a). Growth in the economy is measured by the change in GDP at a constant price. GDP is the most common measure of income for an entire country (Mumford 2016). Usually, higher income or more developed countries will have a higher GDP ranking than lower income or less developed countries. The following paragraphs compare the GDP ranking from the World Bank (The World Bank 2024c) paired with the percentage change in imported calories for a country[2]. One can see that typically countries with higher numerical GDP rankings tend to suffer the most percentage change but there are some countries within the top fifty GDP rankings that experience the most percentage change.

The five countries that experience the most caloric loss when the Panama Canal is closed are El Salvador, Ecuador, Peru, Samoa, and the French Polynesia. Within this group of five countries that experience significant imported calorie loss without the Panama Canal, there are countries on the higher end of GDP size and some on the lower end, therefore showing that not only low-income countries are dependent on these chokepoints.

Table 7.1 GDP ranking comparison of the top five countries experiencing the most change in imported calories under the Panama Canal counterfactual

Country	GDP Rank	Million USD	Percentage Change
El Salvador	104	34,016	-62.00%
Ecuador	63	118,845	-40.31%
Peru	49	267,603	-32.80%
Samoa	198	938	-31.64%
French Polynesia	164	5,815	-29.77%

[2] The World Bank GDP Ranking for 2023 is out of 209 countries.

Looking at the five countries that are most dependent on the Suez Canal based on this regression results, Jordan, Djibouti, Yemen, Iran, and United Arab Emirates make up this group. Again, there is a wide range of economic prosperity of the countries that fall into this group. Yemen does not currently have data available for the year 2023 but can be expected to be on the very low end of the scale in terms of GDP. They have been experiencing a famine and severe conflict within the country that has prevented the country from operating enough to maintain a stable economy and meet their citizens' needs (The World Bank 2024b). United Arab Emirates and Iran are on the lower end of the GDP ranking spectrum and Jordan, Djibouti, and Yemen are on the opposite end.

Table 7.2 GDP ranking comparison of the top five countries experiencing the most change in imported calories under the Suez Canal counterfactual

Country	GDP Rank	Million USD	Percentage Change
Jordan	89	50,967	-81.36%
Djibouti	169	4,099	-74.54%
Yemen	-	-	-70.98%
Iran	36	404,626	-54.09%
United Arab Emirates	27	514,130	-50.69%

Evaluating the countries that are more reliant on the Malacca Strait during their trade routes over sea, Malaysia, Bangladesh, Myanmar, Singapore, and Thailand experience the most change in their imported calories when forced to take alternative routes. Their GDP rankings closely follow the other two counterfactual scenario trends and further confirm that countries of all economic size depend upon these critical maritime passageways.

Table 7.3 GDP ranking comparison of the top five countries experiencing the most change in imported calories under the Malacca Strait counterfactual

Country	GDP Rank	Million USD	Percentage Change
Malaysia	37	399,705	-19.60%
Bangladesh	32	437,415	-7.03%
Myanmar	86	66,758	-5.32%
Singapore	30	501,428	-3.29%
Thailand	26	514,969	-2.47%

Thailand has the highest GDP ranking out of this group and suffers the least change in imported calories out of this group of five at 2.47%. However, they are still among the top five countries to experience the most change in imported calories out of 140 countries. The second highest GDP ranking of this group was Singapore at 30th with 501,428 million USD. Although Myanmar had the smallest GDP, they do not suffer the most change in imported calories, Malaysia does with 19.60% change in imported calories.

From this paper, one can conclude that any type of delay or closure of a critical maritime passageway has significant impact on countries of all economic sizes and power. Disruptions of global value chains and congestion at ports will continue to persist in the near future. Understanding the magnitude of these changes in food security will be important for policy makers, firms, and consumers because it will continue to have detrimental impacts if not addressed. It is difficult for countries that are affected by these chokepoints so severely to address the problem at its core when another country or government may have jurisdiction over the chokepoint. Many import dependent countries may have attempted to put into place policy, resources, and programs to improve domestic production, but few have addressed chokepoint risk (Bailey and Wellesley 2017). Other countries may have had difficulties with investing in supply chain and transportation infrastructure.

With an increase in cost of shipping for companies to take alternative routes, prices of goods may continue to become even more volatile. Products that can easily and cheaply be produced in foreign countries will take longer to reach their markets, causing a dent in countries' comparative advantage strengths. Not all countries will be as impacted as others. These countries may be able to take advantage of the other countries that are forced to take longer trade routes, because transportation costs will be cheaper for the countries experiencing less impacts. They may be able to capitalize on other markets they may not have current access to. The potential for this could widen the gap between developed and developing economies.

Overall, the importance of maritime passageways for trade routes remains high. Congestion at chokepoints along trade routes remains a challenge that needs addressing. Recent events coupled with the results of this study should emphasize the importance of protecting and strengthening infrastructure at these chokepoints and draw attention to action that needs to take place by numerous stakeholders across the globe. Despite the limitations, this study provides strong insight into addressing chokepoint congestion not previously evaluated.

Chapter 8 - References

Alexandratos, N., and J. Bruinsma. 2012. “World agriculture towards 2030/2050: the 2012 revision.” FAO Agricultural Development Economics Division. Available at: https://www.fao.org/4/ap106e/ap106e.pdf.

Anderson, K., M. Ivanic, and W. Martin. 2013. “Food Price Spikes, Price Insulation and Poverty.” No. w19530, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w19530.pdf [Accessed December 30, 2024].

Attinasi, M.G., L. Boeckelmann, L. Hespert, J. Linzenich, and B. Meunier. 2024. “Global trade in the post-pandemic environment.” *European Centeral Bank (ECB) Economic Bulletin* (1). Available at: https://www.ecb.europa.eu/press/economic-bulletin/focus/2024/html/ecb.ebbox202401_01~d1c3b1b0a5.en.html.

Bacchetta, M., C. Beverelli, O. Cadot, M. Fugazza, J.-M. Grether, M. Helble, A. Nicita, and R. Piermartini. 2012. *A Practical Guide to Trade Policy Analysis*. World Trade Organization and United Nations Conference on Trade and Development.

Baier, S.L., J.H. Bergstrand, and M.W. Clance. 2018. “Heterogeneous effects of economic integration agreements.” *Journal of Development Economics* 135:587–608. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0304387818304644 [Accessed March 30, 2025].

Bailey, R., and L. Wellesley. 2017. *Chokepoints and vulnerabilities in global food trade*. London: Chatham House.

Barrett, C.B., T. Reardon, J. Swinnen, and D. Zilberman. 2022. “Agri-food Value Chain Revolutions in Low- and Middle-Income Countries.” *Journal of Economic Literature* 60(4):1316–1377. Available at: https://pubs.aeaweb.org/doi/10.1257/jel.20201539 [Accessed January 9, 2025].

Bendall, H.B. 2010. “Cost of piracy: A comparative voyage approach.” *Maritime Economics & Logistics* 12(2):178–195. Available at: http://link.springer.com/10.1057/mel.2010.1 [Accessed December 18, 2024].

Bergstrand, J.H. 1989. “The Generalized Gravity Equation, Monopolistic Competition, and the Factor-Proportions Theory in International Trade.” *The Review of Economics and Statistics* 71(1):143. Available at: https://www.jstor.org/stable/1928061?origin=crossref [Accessed April 7, 2025].

Bergstrand, J.H. 1985. “The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence.” *The Review of Economics and Statistics* 67(3):474. Available at: https://www.jstor.org/stable/1925976?origin=crossref [Accessed April 7, 2025].

Besley, T., T. Fetzer, and H. Mueller. 2015. “The Welfare Cost of Lawlessness: Evidence from Somali Piracy.” *Journal of the European Economic Association* 13(2):203–239. Available at: https://academic.oup.com/jeea/article-lookup/doi/10.1111/jeea.12114 [Accessed January 22, 2025].

Bird, C. 2024. “Drought at the Panama Canal - Delay, Rising Prices, and other knock-on effects on Global Trade.” *Clyde & Co*. Available at: https://www.clydeco.com/en/insights/2024/01/drought-at-the-panama-canal-delay-rising-prices-an.

Brancaccio, G., M. Kalouptsidi, and T. Papageorgiou. 2020. “Geography, Transportation, and Endogenous Trade Costs.” *Econometrica* 88(2):657–691. Available at: https://www.econometricsociety.org/doi/10.3982/ECTA15455 [Accessed December 16, 2024].

Brenton, P., V. Chemutai, and M. Pangestu. 2022. “Trade and food security in a climate change-impacted world.” *The World Bank*. Available at: https://documents1.worldbank.org/curated/en/099062423145035506/pdf/P17695104b50e7090087fd0f31f76e77f36.pdf.

Brigham, C.L. 2021. “The Suez Canal and Global Trade Routes.” *U.S. Naval Institute* 147/5/1,419(Naval Review). Available at: https://www.usni.org/magazines/proceedings/2021/may/suez-canal-and-global-trade-routes.

Brock, S. 2023. “What is a food system? Exploring enactments of the food system multiple.” *Agriculture and Human Values* 40(3):799–813. Available at: https://link.springer.com/10.1007/s10460-023-10457-z [Accessed February 10, 2025].

Burlando, A., A. Cristea, and L.M. Lee. 2015. “The Trade Consequences of Maritime Insecurity: Evidence from Somali Piracy.” *Review of International Economics* 23(3):41. Available at: https://pages.uoregon.edu/burlando/Current_Research_files/piracy_text_v11%20%28R%26R%29.pdf.

CES at University of North Carolina. 2024. “Chapter 3: What is the European Union?” *Center for European Studies*. Available at: https://europe.unc.edu/toolkits/chapter-3/.

Chico, C., Z. Wang, E.K.C. Reyes, and M.J. Mariasingham. 2024. “Navigating Drought: Analyzing Panama Canal Transit Disruptions Using AIS Big Data.” Available at: https://www.researchsquare.com/article/rs-4193827/v1 [Accessed December 16, 2024].

Clevenger, S. 2021. “Top 50 Global Carriers: Supply Chain Woes Create Challenges for Top 50 Global Freight Carriers.” *Transport Topics* (1):18. Available at: https://pages.ttnews.com/rs/905-BBW-876/images/GFC%202021%20Online.pdf.

Conte, M., P. Cotterlaz, and T. Mayer. 2022. “The CEPII Gravity database.” In CEPII Research and Expertise on the World Economy. Available at: https://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=8.

Conte, M., P. Cotterlaz, and T. Mayer. 2023. “The CEPII Gravity Database Documentation.” Available at: https://www.cepii.fr/DATA_DOWNLOAD/gravity/doc/Gravity_documentation.pdf.

Corrêa, C. 2021. “International trade and the gravity model: recent evidence in theoretical and empirical analysis.” Available at: http://rgdoi.net/10.13140/RG.2.2.11671.70562 [Accessed December 18, 2024].

Costello, M. 2008. “Shipping insurance cost soars with piracy surge off Somalia.” *The Times*.

Crawford, J.-A., and S. Laird. 2000. “Regional Trade Agreements and the WTO.” In 00/3. North American Economic and Finance Assocaition. Centre for Research in Economic Development and International Trade, University of Nottingham, p. 37. Available at: https://www.nottingham.ac.uk/credit/documents/papers/00-03.pdf.

Davis, B., E. Mane, L.Y. Gurbuzer, G. Caivano, N. Piedrahita, N. Azhar, M. Benali, N. Chaudhary, R. Rivera, K. Schneider, R. Ambikapathi, and P. Winters. 2023. *Estimating global and country-level employment in agrifood systems*. FAO. Available at: http://www.fao.org/documents/card/en/c/cc4337en [Accessed January 9, 2025].

Dickinson, R., and G. Zemaityte. 2021. “How has Covid affected global trade?” Bank of England. Available at: https://www.bankofengland.co.uk/bank-overground/2021/how-has-covid-affected-global-trade.

Eaton, J., and S. Kortum. 2002. “Technololgy, Geography, and Trade.” *The Econometric Society* 70(5):1741–1779. Available at: https://economics.yale.edu/sites/default/files/2024-02/Eaton-TechnologyGeographyTrade-2002.pdf.

Eavis, P., and N. Angarita. 2023. “Drought Saps the Panama Canal, Disrupting Global Trade.” *New York Times Company*. Available at: https://www.nytimes.com/2023/11/01/business/economy/panama-canal-drought-shipping.html.

European Union. 2024. “European-Union.” *Trade*. Available at: https://european-union.europa.eu/priorities-and-actions/actions-topic/trade_en#:~:text=The%20European%20Union%20is%20one,negotiating%20trade%20agreements%20or%20rules.

FAO Agriculture and Development Economics Division. 2006. “Food Security.” Policy Brief No. 2, Food and Agriculture Organization. Available at: https://www.fao.org/fileadmin/templates/faoitaly/documents/pdf/pdf_Food_Security_Cocept_Note.pdf.

FAOSTAT. 2024. “Detailed Trade Matrix.” Available at: https://www.fao.org/faostat/en/#data/TM.

Feingold, S. 2023. “‘Unprecedented challenges’: Drought at the Panama Canal disrupts global trade.” *World Economic Forum*. Available at: https://www.weforum.org/stories/2023/08/drought-at-the-panama-canal-poses-unprecedented-challenges-to-global-trade/.

Fidrmuc, Jan, and Jarko Fidrmuc. 2016. “Foreign languages and trade: evidence from a natural experiment.” *Empirical Economics* 50(1):31–49. Available at: http://link.springer.com/10.1007/s00181-015-0999-7 [Accessed February 10, 2025].

Food and Agricultural Organization. 2001. *Food Balance Sheets A handbook*. FAO. Available at: https://www.fao.org/4/X9892E/X9892e05.htm#P8217_125315.

Food and Agricultural Organization. 2022. *The State of Agricultural Commodity Markets 2022*. FAO. Available at: http://www.fao.org/documents/card/en/c/cc0471en [Accessed February 17, 2025].

Francois, J., A.M. Leister, and H. Rojas-Romagosa. 2015. “Melting Ice Caps: Implications for Asia-North America Linkages and the Panama Canal.” In 17th Annual Conference on Global Economic Analysis, Dakar, Senegal. Global Trade Analysis Project, p. 46. Available at: https://ageconsearch.umn.edu/record/332671/?ln=en&v=pdf.

Frankel, J.A., and A.K. Rose. 1998. “The Endogenity of the Optimum Currency Area Criteria.” *The Economic Journal* 108(449):1009–1025. Available at: https://academic.oup.com/ej/article/108/449/1009-1025/5128584 [Accessed February 10, 2025].

Frankenberg, E., and D. Thomas. 2017. “Human Capital and Shocks: Evidence on Education, Health and Nutrition.” No. w23347, National Bureau of Economic Research. Available at: http://www.nber.org/papers/w23347.pdf [Accessed December 30, 2024].

Freeman, R., and J. Lewis. 2021. “Gravity model estimates of the spatial determinants of trade, migration, and trade-and-migration policies.” *Economics Letters* 204:109873. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0165176521001506 [Accessed March 30, 2025].

Freeman, R., and S. Pienknagura. 2019. “Are all trade agreements equal? The role of distance in shaping the effect of economic integration agreements on trade flows.” *Review of World Economics* 155(2):257–285. Available at: http://link.springer.com/10.1007/s10290-018-0327-3 [Accessed March 30, 2025].

Gaffuri, J. 2024. “Searoute.” Available at: https://github.com/eurostat/searoute [Accessed September 26, 2024].

Gettleman, J. 2009. “For Somalia Pirates, Worst Enemy May Be on Shore.” *The New York Times*.

Global Migration Data Analysis Centre. 2022. “Migration Data Portal: Urbanization and migration.” *Migration Data Portal*. Available at: https://www.migrationdataportal.org/themes/urbanization-and-migration#:~:text=A%20majority%20and%20growing%20proportion,population%20(UN%2C%202018).

Goldberg, P. 2016. “The Effects of Trade Policy.” Available at: https://www.nber.org/system/files/working_papers/w21957/w21957.pdf [Accessed February 10, 2025].

Gollin, D. 2010. “Chapter 73 Agricultural Productivity and Economic Growth.” In *Handbook of Agricultural Economics*. Elsevier, pp. 3825–3866. Available at: https://linkinghub.elsevier.com/retrieve/pii/S1574007209040730 [Accessed January 4, 2025].

Goodman, P., and S. Reed. 2021. “Ships Consider Rerouting to Bypass Suez Canal.” *New York Times Company*.

Grant, J.H., and K.A. Boys. 2012. “Agricultural Trade and the GATT/WTO: Does Membership Make a Difference?” *American Journal of Agricultural Economics* 94(1):1–24. Available at: https://onlinelibrary.wiley.com/doi/10.1093/ajae/aar087 [Accessed March 24, 2025].

Gurevich, T., and P.R. Herman. 2018. “Dynamic Gravity Dataset: 1948-2016.” Available at: https://www.usitc.gov/data/gravity/dgd.htm.

Gurevich, T., P.R. Herman, N. Abbyad, M. Demirkaya, A. Drenski, J. Horowitz, and G. Kenneally. 2018. “The Dynamic Gravity Dataset: Technical Documentation.” Available at: https://www.usitc.gov/data/gravity/dynamic_gravity_technical_documentation_v1_00_0.html.

He, Z., C. Wang, J. Gao, and Y. Xie. 2023. “Assessment of global shipping risk caused by maritime piracy.” *Heliyon* 9(10):e20988. Available at: https://linkinghub.elsevier.com/retrieve/pii/S2405844023081963 [Accessed December 16, 2024].

Head, K., and T. Mayer. 2014. “Gravity Equations: Workhorse,Toolkit, and Cookbook.” In *Handbook of International Economics*. Elsevier, pp. 131–195. Available at: https://linkinghub.elsevier.com/retrieve/pii/B9780444543141000033 [Accessed December 18, 2024].

Herman, P.R. 2023. “Gravity Estimation: Best Practices and Useful Approaches.” Available at: https://www.usitc.gov/publications/332/working_papers/herman_gravity_estimation_practices_2023.pdf.

ICC International Maritime Bureau. 2025. “Piracy and Armed Robbery against ships.” ICC International Maritime Bureau. Available at: https://icc-ccs.org/wp-content/uploads/2025/01/2024-Jan-Dec-IMB-Piracy-and-Armed-Robbery-Report-2.pdf.

Kabir, M., R. Salim, and N. Al-Mawali. 2017. “The gravity model and trade flows: Recent developments in econometric modeling and empirical evidence.” *Economic Analysis and Policy* 56:60–71. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0313592617300899 [Accessed April 7, 2025].

Kilfoyle, M. 2023. “Ukraine: what’s the global economic impact of Russia’s invasion?” *Economics Observatory*. Available at: https://www.economicsobservatory.com/ukraine-whats-the-global-economic-impact-of-russias-invasion.

Kravchenko, A., and H. Doytchinova. 2020. “ESCAP Online Training on Using R for Trade Analysis.” *United Nations ESCAP Training on Using R for Trade Analysis*. Available at: https://r.tiid.org/gravity-models.html.

Larsen, M.C. 2019. “Water Supply and Water Quality Challenges in Panama.” In *Advances in Water Purification Techniques*. Elsevier, pp. 41–66. Available at: https://linkinghub.elsevier.com/retrieve/pii/B978012814790000003X [Accessed December 18, 2024].

Lee, J.M., and E.Y. Wong. 2021. “Suez Canal blockage: an analysis of legal impact, risks and liabilities to the global supply chain” P. Khvedelidze, B. Gechbaia, and K. Goletiani, eds. *MATEC Web of Conferences* 339:01019. Available at: https://www.matec-conferences.org/10.1051/matecconf/202133901019 [Accessed December 16, 2024].

Leibovici, F., and T. Adamopoulos. 2024. “Trade Risk and Food Security.” Available at: https://s3.amazonaws.com/real.stlouisfed.org/wp/2024/2024-004.pdf [Accessed December 28, 2024].

Leitão, N.C. 2024. “Gravity Model and International Trade: A Survey of the Literature.” *Administrative Sciences* 14(9):219. Available at: https://www.mdpi.com/2076-3387/14/9/219 [Accessed April 7, 2025].

Liu, X., E. Ornelas, and H. Shi. 2022. “The trade impact of the COVID-19 pandemic.” *The World Economy* 45(12):3751–3779. Available at: https://onlinelibrary.wiley.com/doi/10.1111/twec.13279 [Accessed December 16, 2024].

Ly, T.D., P.X. Dong, L.H. Anh, and P.T. Ha An. 2020. “The Effect of International Trade on Food Security at Southeast Asian Countries.” *WSEAS TRANSACTIONS ON ENVIRONMENT AND DEVELOPMENT* 16:180–188. Available at: https://wseas.com/journals/ead/2020/a365115-050.pdf [Accessed December 28, 2024].

Márquez-Ramos, L., and I. Martínez-Zarzoso. 2008. “On Distance Effects in Gravity Models — Short Versus Long Distances.” In G. Tondl, ed. *Trade, Integration and Economic Development*. Schriftenreihe der Österreichischen Gesellschaft für Europaforschung (ECSA Austria) / European Community Studies Association of Austria Publication Series. Vienna: Springer Vienna, pp. 151–167. Available at: http://link.springer.com/10.1007/978-3-211-75150-3_8 [Accessed March 30, 2025].

Mayer, T., and S. Zignago. 2005. “Market Access in Global and Regional Trade.” *CEPII Working Paper* (2):45. Available at: https://www.cepii.fr/PDF_PUB/wp/2005/wp2005-02.pdf.

Melitz, J., and F. Toubal. 2014. “Native language, spoken language, translation and trade.” *Journal of International Economics* 93(2):351–363. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0022199614000543 [Accessed February 10, 2025].

Mumford, K.J. 2016. “Prosperity, Sustainability and the Measurement of Wealth.” *Asia & the Pacific Policy Studies* 3(2):226–234. Available at: https://onlinelibrary.wiley.com/doi/10.1002/app5.132 [Accessed December 28, 2024].

New Zealand Embassy (Cairo). 2021. “The Importance of the Suez Canal to Global Trade.” MFAT Market Intelligence Reports New Zealand Foreign Affairs & Trade. Available at: https://www.mfat.govt.nz/en/trade/mfat-market-reports/the-importance-of-the-suez-canal-to-global-trade-18-april-2021.

Notteboom, T., A. Pallis, and J.-P. Rodrigue. 2021. *Port Economics, Management and Policy* 1st ed. London: Routledge. Available at: https://www.taylorfrancis.com/books/9780429318184 [Accessed February 7, 2025].

Payosova, T., G.C. Hufbauer, and J.J. Schott. 2018. “18-5 The Dispute Settlement Crisis in the World Trade Organization: Causes and Cures.” No. 5, Peterson Institute for International Economics. Available at: https://www.piie.com/sites/default/files/documents/pb18-5.pdf.

PCA. 2023. “Weekly update on transits through the Panama Canal.” *Panama Canal Authority*. Available at: https://pancanal.com/en/weekly-update-on-transits-through-the-panama-canal/.

PCA (Panama Canal Authority). 2024. “End Of The Construction.” *Canal De Panamá*. Available at: https://pancanal.com/en/end-of-the-construction/.

Pfaffermayr, M. 2023. “Cross-sectional Gravity Models, PPML Estimation, and the Bias Correction of the Two-Way Cluster-Robust Standard Errors*.” *Oxford Bulletin of Economics and Statistics* 85(5):1111–1134. Available at: https://onlinelibrary.wiley.com/doi/10.1111/obes.12553 [Accessed December 18, 2024].

Port of Los Angeles. 2024. “About Tonnage Statistics.” *The Port of Los Angeles*. Available at: https://www.portoflosangeles.org/business/statistics/tonnage-statistics.

Runge, C.F. ed. 2003. *Ending hunger in our lifetime: food security and globalization*. Baltimore, MD: Johns Hopkins University Press.

Russon, M.-A. 2021. “The cost of the Suez Canal blockage.” *BBC*. Available at: https://www.bbc.com/news/business-56559073.

Ruta, M. 2022. “The Impact of the War in Ukraine on Global Trade and Investment.” No. 170848, World Bank.

Samuelson, P.A. 1952. “The Transfer Problem and Transport Costs: The Terms of Trade When Impediments are Absent.” *The Economic Journal* 62(246):278. Available at: https://academic.oup.com/ej/article/62/246/278-304/5260751 [Accessed December 18, 2024].

Sandkamp, A., V. Stamer, and S. Yang. 2022. “Where has the rum gone? The impact of maritime piracy on trade and transport.” *Review of World Economics* 158(3):751–778. Available at: https://link.springer.com/10.1007/s10290-021-00442-1 [Accessed December 16, 2024].

Schott, J.J., and E. Jung. 2019. “19-19 The WTO’s Existential Crisis: How to Salvage Its Ability to Settle Trade Disputes.” No. 19, Peterson Institute for International Economics. Available at: https://www.piie.com/sites/default/files/documents/pb19-19.pdf.

Smith, C.G., and W.B. Fisher. 2024. “Suez Canal.” Available at: https://www.britannica.com/topic/Suez-Canal.

Smith, V.H., and J.W. Glauber. 2020. “Trade, policy, and food security.” *Agricultural Economics* 51(1):159–171. Available at: https://onlinelibrary.wiley.com/doi/10.1111/agec.12547 [Accessed December 30, 2024].

Steinbach, S. 2023. “The Russia–Ukraine war and global trade reallocations.” *Economics Letters* 226:111075. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0165176523001003 [Accessed December 16, 2024].

Sytsma, T., and W.W. Wilson. 2020. “Port Choice and International Trade in Agricultural Products.” *University of Oregon*:41. Available at: https://trforum.org/wp-content/uploads/2020/03/Port-Choice.pdf.

The Port of Los Angeles. 2024. “US Trade Numbers.” *The Port of Los Angeles*. Available at: https://ustradenumbers.com/port/port-of-los-angeles/.

The World Bank. 2024a. “Economy.” *The World Bank*. Available at: https://datatopics.worldbank.org/world-development-indicators/themes/economy.html#:~:text=Gross%20Domestic%20Product%20(GDP)%2C,in%20GDP%20at%20constant%20price.%20.

The World Bank. 2024b. “Food Security Update.” Available at: https://thedocs.worldbank.org/en/doc/40ebbf38f5a6b68bfc11e5273e1405d4-0090012022/related/Food-Security-Update-111-December-13-2024.pdf.

The World Bank. 2024c. “GDP Ranking.” Available at: https://datacatalog.worldbank.org/search/dataset/0038130.

Timmer, C.P. 2009. *A world without agriculture: the structural transformation in historical perspective*. Washington, D.C: AEI Press. Available at: https://www.aei.org/wp-content/uploads/2014/06/-a-world-without-agriculture-the-structural-transformation-in-historical-perspective_145442400043.pdf.

Trefler, D. 1993. "Trade Liberalization and the Theory of Endogenous Protection: An Econometric Study of U.S. Import Policy." *Journal of Political Economy* 101(1):138–160. Available at: https://www.journals.uchicago.edu/doi/10.1086/261869 [Accessed December 18, 2024].

United Nations Trade and Development. 2024. "Disruptions in key global shipping route - Suez Canal, Panama Canal, and Black Sea - signal unprecedented challenges for global trade affecting millions of people in every region." United Nations Trade and Development. Available at: https://unctad.org/press-material/disruptions-key-global-shipping-route-suez-canal-panama-canal-and-black-sea-signal#:~:text=Approximately%2022%25%20of%20total%20Chilean%20and%20Peruvian%20foreign,countries%20is%20highly%20dependent%20on%20the%20Suez%20Canal.

United States Department of Agriculture: Agriculture Marketing Service. 2017. "Export/Import Profile New Orleans, LA Port Region." United States Department of Agriculture: Agriculture Marketing Service. Available at: https://www.ams.usda.gov/sites/default/files/NewOrleansPort.pdf.

United States International Trade Commission. 2021. "The Dynamic Gravity Dataset: Technical Documentation Update Note." Available at: https://www.usitc.gov/data/gravity/gravity_dataset_documentation_version_2_1.pdf.

U.S. National Geospatial-Intelligence Agency. 2019. "World Port Index." Available at: https://msi.nga.mil/Publications/WPI.

USITC. 2020. "The Impact of the COVID-19 Pandemic on Freight Transportation Services and U.S. Merchandise Imports." Available at: https://www.usitc.gov/research_and_analysis/tradeshifts/2020/special_topic.html.

Vicard, V. 2011. "Determinants of successful regional trade agreements." *Economics Letters* 111(3):188–190. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0165176511000607 [Accessed March 30, 2025].

Wang, X., L. Ma, S. Yan, X. Chen, and A. Growe. 2023. "Trade for Food Security: The Stability of Global Agricultural Trade Networks." *Foods* 12(2):271. Available at: https://www.mdpi.com/2304-8158/12/2/271 [Accessed December 28, 2024].

World Bank. 2012. *World Development Indicators 2012*. Washington, DC.

World Food Programme. 2024. "WFP 2025 Global Outlook." World Food Programme.

World Population Review. 2023. “World Population Review.” *World Population Review*. Available at: https://worldpopulationreview.com/.

World Shipping Council. 2023. “The Top 50 Container Ports.” Available at: https://www.worldshipping.org/top-50-ports.

Wright, B.D. 2012. “International Grain Reserves And Other Instruments to Address Volatility in Grain Markets.” *The World Bank Research Observer* 27(2):222–260. Available at: https://academic.oup.com/wbro/article-lookup/doi/10.1093/wbro/lkr016 [Accessed December 30, 2024].

Wu, Z., H. Cai, R. Zhao, Y. Fan, Z. Di, and J. Zhang. 2020. “A Topological Analysis of Trade Distance: Evidence from the Gravity Model and Complex Flow Networks.” *Sustainability* 12(9):3511. Available at: https://www.mdpi.com/2071-1050/12/9/3511 [Accessed March 30, 2025].

Yoto V. Yotov, Roberta Piermartini, José-Antonio Monteiro, and and Mario Larch. 2016. *An Advanced Guide to Trade Policy Analysis: The Strucural Gravity Model*. World Trade Organization and United Nations Conference on Trade and Development. Available at: https://www.wto.org/english/res_e/booksp_e/advancedwtounctad2016_e.pdf.

Zilberman, D., T. Reardon, J. Cooper, and S. Shoemaker. 2023. “Thinking in Terms of Supply Chains Rather Than Individuals Markets.” *Giannini Foundation of Agricultural Economics, University of California*. Available at: https://s.giannini.ucop.edu/uploads/pub/2023/05/03/v26n4_2.pdf.

Appendix A - Port Selection

Within software R: (description of transformations/cleaning of the data CSV file)

Cleaned the U.S. National Geospatial-Intelligence Agency's World Port Index dataset by eliminating columns that did not pertain to this study. In addition, divided the ports and grouped them by size of the port/harbor. There were four categories: Large, Medium, Small, and Very Small. There were some ports included in another category that acted as a catch all. The countries and their ports included in this category were excluded from this analysis because they were not the largest or main ports of the country.

Once the countries were grouped based on size, I filtered down to choose the largest port for each country. For example, the United States has port sizes of all categories. However, I excluded the ports belonging to the Medium, Small, and Very Small groups because the U.S. contained a port in the Large port size group. Another example, the largest port in Paraguay is of the port size Very Small. Paraguay had no ports included in the Large, Medium, or Small port sized groups. Once the countries were grouped based on the largest size of their ports, I then further filtered down the ports. For example, the United States had 21 large sized ports. To choose one port I consulted online resources to compare ports and ultimately choose the port that handled the most cargo, had the most traffic, located nearest to the capital or to the largest populated city within the country. In the table below, I list the sole reason for choosing that specific port for each country within the dataset. I then put one port (or in some countries' case, two ports) for each country into a separate dataset based on the port name. When I filtered using port names there were some countries that had the same port name as other countries. I dropped the observations of those countries that had duplicated port names that did not belong to that port size group. For example, in the Small port sized group, Canada has a port named St. George's but so does Grenada. Canada has much large ports and belongs to the Large port group. I dropped the Canada observation from the Small port group and kept the Grenada observation because their largest port was a Small sized port. I then combined all these separate port groups into one port database to then use the coordinates to calculate the distances between ports for each country. I used the software Searoute developed by Gaffuri, 2024 to calculate these distances. The distances Searoute provided were then included in calculating the gravity model. Note: Antarctica is not included in this port selection and analysis.

Source for capitals of each country: Maps of World. Countries and Capitals. 2024. https://www.mapsofworld.com/countries-capitals/

Appendix Table A.1 Countries with two ports

Atlantic ports	Pacific ports	Country
Montreal	Vancouver	Canada
Barranquilla	Buenaventura	Colombia
Puerto Limon	Golfito	Costa Rica
Santo Tomas De Castillo	Puerto Quetzal	Guatemala
Veracruz	Manzanillo	Mexico
Bluefields	Corinto	Nicaragua
Puerto Cristobal	Balboa	Panama
Novorossiysk	Vladivostok	Russia

Appendix Table A.2 Large Sized Ports

Port:	Country:	Statement:
Alger	Algeria	Located in the capital city. Listed as the largest port in the country and is considered the main port[1]. Handles over 20 million tons of cargo annually[2] and in 2019 handled over 444,621 TEUs[1]
Buenos Aires	Argentina	Argentina's largest port and located in the capital city. Some might consider this country to have two oceans, but for the size and consideration, I am only selecting one port.
Melbourne	Australia	Melbourne is the second most populated city in Australia. Largest port in terms of size[3]. Had 107,600,278 tonnes of cargo in 2022[4].
Antwerpen	Belgium	Largest port in Belgium according to WPI.
Santos	Brazil	In the top 50 largest ports in the world[5] and is the largest in Brazil[6]. Annually had 4.2 million TEUs of container transactions[5,7].
Varna	Bulgaria	Largest port in Bulgaria according to WPI.
Montreal	Canada (East)	A major metropolis in Canada. Main port on the east coast[8]. Handled 36 million tonnes of cargo in 2022[8]. Geographic location on the coast. Chose two ports for the country because of the size and because there are large ports on both the Atlantic and Pacific oceans.
Vancouver	Canada (West)	Major metropolis in Canada. Main port on the west coast. Largest port in Canada[8]. Handled 141.2 million tonnes in 2022 and

Port:	Country:	Statement:
		146.5 million tonnes in 2021[8,9]. In 2023, handled 150 million tonnes of cargo[9].
Shanghai	China, mainland	Over 25 million people live here. One of the major metropolises of China. Good geographic location for China. It is the largest port in the world[5,10].
Abidjan	Cote De'Ivorie	Largest port in Cote De'Ivorie according to WPI.
Rijeka Luka	Croatia	Handled 12,809,186 tons of cargo in 2023[11]. General cargo volume increased by 9% in 2022 to 719,094 tonnes, while bulk cargo volume also went up by 4%. [12]
Bahai De La Habana	Cuba	Located in the capital of Cuba and is the most populated city in Cuba.
Kobenhavn	Denmark	Located in the capital and is their largest city.
Al Iskandariyh (Alexandria)	Egypt	Handles around three-fourths of the nation's maritime trade and generates around 60% of trade revenue[13]. In November 2023, had 4,839,270 tons of cargo[14].
Muuga-Port of Tallinn	Estonia	Located in the capital city.
Helsinki	Finland	Number one general port for international freight traffic in Finland[15,16]. Total throughput was 14.3 million tonnes[15].
Port of Le Havre	France	Listed as a major port within the ISEMAR "French ports & yards analytic overview" and is one also considered a large port in the WPI dataset[17].

Port:	Country:	Statement:
Hamburg	Germany	Largest seaport in Germany and is the third largest in Europe[18,19].
Piraievs	Greece	Located in the capital city (sub city of Athens).
Hong Kong	Hong Kong	Located in the capital city.
Mumbai (Bombay)	India	Largest port in India according to WPI.
Jakarta	Indonesia	Located in the capital city. There are several islands that make up Indonesia that have many seas and oceans that surround them. Due to the size of the country, I am only selecting one port. The capital has the largest population of people living there so it does reach many citizens.
Foynes	Ireland	Largest port in Ireland according to WPI.
Genova	Italy	Largest port in Italy according to WPI and has throughput of 63.7 million tons total[20].
Tokyo Ko	Japan	Located in the capital city.
Riga	Latvia	Located in the capital city.
Bayrut	Lebanon	Largest port in Lebanon according to WPI.
Port Klang	Malaysia	The country does have two oceans on each side; however, I am only choosing one port because of the port's size relative to others and for the size of the country. Considered in the Top 50 ports of the world[5]. 38% of the nation’s international maritime trade passes through this facility[21].
Tangier-Mediterranean	Morocco	Listed within the Top 50 Ports in the World[5]. Tanger Med Port Authority reported 122 million tons of cargo[22].

Port:	Country:	Statement:
Rotterdam	Netherlands	Listed within the Top 50 Ports in the World[5]. Saw 220.0 million tonnes in the first half of 2024[23].
Auckland	New Zealand	Port of Auckland was chosen because the Port of Tauranga has the largest exports[24,25]. Auckland is cited as New Zealand's main port[26] and handles over 31% of the country's total container volume[25].
Lagos	Nigeria	Listed as the main port[27,28].
Oslo	Norway	Capital city and the main population is located here. Choosing only one port for this country based on size and only two seas border this country. The Norwegian Sea is more difficult for many countries to sail in and out of without passing through the North Sea.
Manila	Philippines	Located in the capital city.
Gdansk	Poland	Largest port in Poland and handled around 81 million metric tons of cargo in 2023[29,30].
Lisboa	Portugal	The capital city and the main population are here.
Novorossiysk	Russia (East - Atlantic)	Novorossiysk is in the Black Sea and Sankt-Peterburg is in the Baltic Sea. Both are on the East side.
Vladivostok	Russia (West - Pacific)	Largest port on the West side of Russia.
Jurong Island	Singapore	Located just west of the capital city.
Cape Town	South Africa	Located in the capital city. Only choosing one port for this country because it lies at

Port:	Country:	Statement:
		the tip of Africa and may be considered in two oceans, but I am only considering one port. In addition, the size of the country also contributes to selecting only one port.
Busan	South Korea	Listed as the largest and busiest port in South Korea with 434,668,799 tons of cargo in 2023[31,32].
Barcelona	Spain	Listed in WPI as a large port even though other sources list it as the third largest port[33,34]. Has 9,000 vessels annually with 63 million tons of cargo per year[33,34].
Goteborg (Gothenburg)	Sweden	Listed as the largest in Sweden with 914,000 containers passing through each year[35,36].
Baniyas	Syria	The Arab Sea Ports Federation lists Latakia as a medium sized port[37]. Tartous is one of two major ports[37]. The other being Baniyas.
Chi-Lung	Taiwan	Also known as Keelung. Handles 3,000 vessels annually[38]. Listed as the largest in WPI.
Bangkok	Thailand	Located in the capital city. Only choosing one port because the stretch of border that includes another ocean is not large enough to have a port for transporting goods.
Istanbul	Turkey	Listed as the largest port in WPI and handles around 60 million metric tons on average[39].

Port:	Country:	Statement:
Odesa	Ukraine	Annual cargo capacity of 40 million tonnes and is credited to be the largest port in Ukraine[40,41].
Mina Jabal Ali	United Arab Emirates	Largest port in the United Arab Emirates according to WPI.
London	United Kingdom	Located in the capital near majority of the population
New Orleans	United States	Main grain trade flows out of here on the east side. Choosing only one port for this country because most of the agricultural products are shipped in and out of this port (United States Department of Agriculture: Agriculture Marketing Service 2017).
Puerto La Cruz	Venezuela	Largest port in Venezuela according to WPI.
Ras Isa Marine Terminal	Yemen	Largest port in Yemen according to WPI.

Appendix Table A.3 Medium Sized Ports

Port:	Country:	Statement:
St. Johns	Antigua and Barbuda	Located in the capital city.
Mina Salman	Bahrain	Located very near the capital city or could be considered part of the capital city.
Chittagong	Bangladesh	Largest port in Bangladesh according to WPI.
Cotonou	Benin	Near the capital city but not based directly in the capital city.
Kampong Saom	Cambodia	Largest port in Cambodia according to WPI.
Douala	Cameroon	Largest port in Cameroon according to WPI.
Bahia De Valparaiso	Chile	Located in central Chile.
Macau	China, Macao SAR	Largest port in China, Macao SAR according to WPI.
Barranquilla	Colombia (East)	Choosing two ports for this country because it has large enough coastline in both the Atlantic and Pacific oceans. The port on the Pacific side is listed in the small ports table.
Santo Domingo	Dominican Republic	Located in the capital city
Libreville	Gabon	Located in the capital city.
Takoradi	Ghana	Largest port in Ghana according to WPI.
Conakry	Guinea	Located in the capital city.
Georgetown	Guyana	Located in the capital city.
Reykjavik	Iceland	Located in the capital city. Only choosing one port for this country because of the size of the country.

Port:	Country:	Statement:
Bandar Abbas	Iran	Listed as the main port in Iran and handles 37,000,000 tonnes of cargo annually[83].
Haifa	Israel	Listed as the main port in Israel and handles over 30 million tons of cargo every year[84].
Kingston	Jamaica	Located in the capital city.
Mombasa	Kenya	Largest port in Kenya according to WPI.
Mina Tarabulus (Tripoli)	Libya	Located in the capital city.
Klaipeda	Lithuania	Largest port in Lithuania according to WPI.
Valletta Harbors	Malta	Located in the capital city.
Nouadhibou	Mauritania	Largest port in Mauritania according to WPI.
Veracruz	Mexico (East)	Mexico City is the capital. Choosing two ports for this country because it has ports of large enough sizes in both the Pacific and Atlantic oceans and is a large agricultural exporter. This is the largest port on the Atlantic side (WPI dataset).
Manzanillo	Mexico (West)	Listed as the largest port in Mexico[42]. It's also the port with the largest tonnage (3.18 million as of 2021)[43].
Maputo	Mozambique	Located in the capital city.
Duqm	Oman	Largest port in Oman according to WPI.
Karachi	Pakistan	Largest city in Pakistan population wise. Handled 40.241 million tons of cargo in 2023[44].

Port:	Country:	Statement:
Puerto Cristobal	Panama (East)	Choosing two ports for this country because it has ports of great enough size in both the Pacific and Atlantic oceans. Port Manzanillo was not listed as a large port in the WPI dataset. Largest port on the Atlantic side[45].
Balboa	Panama (West)	Largest port on the Pacific side and was included in the largest group of ports for Panama from the WPI dataset[45].
Puerto Del Callao	Peru	Largest port in Peru according to WPI.
Ras Laffan	Qatar	Largest port in Qatar according to WPI.
Constanta	Romania	Listed as the largest port in Romania[46]. In 2023, there were 4,281,333 tonnes of general cargo[47].
Ras Tannurah	Saudi Arabia	Largest port in Saudi Arabia according to WPI.
Dakar	Senegal	Largest port in Senegal according to WPI.
Colombo	Sri Lanka	Listed as the largest port in Sri Lanka[48]. Handles 90% of the country's seaborne goods[49].
Dar Es Salaam	Tanzania	Largest port in Tanzania according to WPI.
Nassau	The Bahamas	Located in the capital city
Lome	Togo	Located in the capital city.
Port of Spain	Trinidad and Tobago	Located in the capital city.
Tunis	Tunisia	Located in the capital city. Choose this port based on that it is in the capital city and large population center.
Montevideo	Uruguay	Located in the capital city.
Thanh Ho Chi Minh	Vietnam	Largest port in Vietnam according to WPI.

Appendix Table A.4 Small Sized Ports

Port:	Country:	Statement:
Durres	Albania	Largest port in Albania according to WPI.
Luanda	Angola	Listed as Angola's main port and is where 80% of the import and export of the country takes place[50,51].
Bridgetown	Barbados	Located in the capital city.
Belize City	Belize	Largest port in Belize according to WPI.
Neum	Bosnia and Herzegovina	Largest port in Bosnia and Herzegovina according to WPI.
Muara Harbor	Brunei	Listed as the largest port in Brunei[52,53].
Rangoon	Myanmar (Burma)	Also known as Yangon port. Formally known as Rangoon (as is known in the WPI CSV file). Largest port in Myanmar and handles more than 90% of the country's normal exports and imports[54,55].
Porto Da Praia	Cabo Verde	Located in the capital city
Buenaventura	Colombia (West)	Largest port on the Pacific side. Handles quite a bit of agricultural products in and out. Overall handles about 8,550,000 tonnes of cargo annually[77].
Pointe Noire	Congo (Brazzaville)	Largest port in Congo according to WPI dataset. Handles approximately 2,840,000 tons of cargo annually[85].
Matadi	Congo (Kinshasa) --> Democratic Republic of Congo	Kinshasa is the capital city. It is the largest port with 350 vessels annually and annually handles 350,000 tonnes of general cargo[56].
Golfito	Costa Rica (West)	Largest port in Costa Rica according to WPI dataset. Choosing two ports for this country because it has a border on both the

Port:	Country:	Statement:
		Atlantic and Pacific Ocean. The other port is the largest on the Atlantic side (but is listed as Very Small size in the WPI dataset).
Limassol	Cyprus	Listed as the largest port in Cyprus and handles 4,670,000 tonnes of cargo annually[57,58].
Djibouti	Djibouti	Located in the capital city.
Guayaquil	Ecuador	Main port in Ecuador and located in the largest city[59].
Suva	Fiji	Listed as the country's busiest port and it is in the capital city[60]. Imports 757,000 tonnes of cargo and exports over 184,000 tonnes of cargo[61].
Papeete	French Polynesia	Located in the capital city.
Batumi	Georgia	Largest port in Georgia according to WPI.
St George's	Grenada	Located in the capital city.
Santo Tomas De Castillo	Guatemala (East)	Choosing two ports for this country because it is situated between the Atlantic and Pacific Ocean and its geographic proximity to the Panama Canal. The second Guatemala port (West) is listed in the Very Small port section. This port is the largest in Guatemala on the Atlantic side. In 2013, it handled 29% of the total cargo[62].
Puerto Cortes	Honduras	Choosing only one port for this country because the second port that would be chosen on the Pacific side is too small to be considered for this analysis. Listed as the

Port:	Country:	Statement:
		largest in Honduras according to WPI dataset.
Toamasina	Madagascar	Listed as the largest port in Madagascsr handling 80% of the nation's international maritime traffic and 1,600,000 tonnes of cargo each year[64,65].
Port Louis	Mauritius	Located in the capital city.
Bar	Montenegro	Largest port in Montenegro[78,79].
Walvis Bay	Namibia	Handles approximately 5-8 million tonnes of cargo and is Nambia's largest port[66,67].
Noumea	New Caledonia	Located in the capital city. Almost 11 million tonnes transported in 2019. [68]
Bluefields	Nicaragua (East)	Choosing two ports for this country because it is situated between the Atlantic and Pacific Ocean and its geographic proximity to the Panama Canal. It is the largest on the Atlantic side[70].
Corinto	Nicaragua (West)	One of Nicaragua's most important ports[69,70]. Some agricultural products arrive and leave here.
Port of Moresby	Papua New Guinea	Port Moresby is the capital city. Some sources will say Lae port is larger, but it is listed as a very small port within the WPI.
Castries	Saint Lucia	Located in the capital city. Chose this port based off the number of ships that are handled annually (1,400) compared to Grand Cul De Sac Bay Port (120 vessels) [71].

Port:	Country:	Statement:
Kingstown	Saint Vincent and the Grenadines (Windward Islands)	Located in the capital city.
Freetown	Sierra Leone	Located in the capital city.
Koper	Slovenia	Largest port in Slovenia according to WPI.
Noro	Solomon Islands	Port Noro has more traffic than Port of Honiara[72].
Paramaribo	Suriname	Located in the capital city.

Appendix Table A.5 Extra Small Sized Ports

Port:	Country:	Statement:
Moutsamoudu	Comoros	Second largest city in Comoros and is the only deep-water port in Comoros and has the largest transit of goods per year[73].
Avatiu	Cook Islands	Largest port in the Cook Islands according to WPI.
Puerto Limon	Costa Rica (East)	On the Atlantic Ocean side and is largest port on that side. Located near Panama Canal. It is listed as the largest port in the country[76] but the WPI does not list it as the largest. Still handles a large amount of cargo.
Roseau	Dominica	Located in the capital city. According to Shipnext.com, Roseau handles more cargo annually (369,000 tons) than Portsmouth (289,000 tons) [81].
Acajutla	El Salvador	Handles some agricultural products in and out of the country. Overall handles 4,500,000 metric tons of cargo annually[74,75].
Torshavn	Faroe Islands	Located in the capital city.
Puerto Quetzal	Guatemala (West)	Handles most of the grain coming into and out of the country. Handles 358,000 containers annually[62,63].
Al Aqabah	Jordan	Largest port in Jordan and handles around 1,000 tons of cargo per day[80].
Al Kuwayt	Kuwait	Located in the capital city. Chose this one because it is closest to the capital city. Others may think differently.
Male	Maldives	Located in the capital city.

Port:	Country:	Statement:
Puerto De Asucion	Paraguay	Located in the capital city.
Basseterre	Saint Kitts and Nevis	Located in the capital city.
Apia	Samoa	Located in the capital city.
Sao Tome	Sao Tome and Principe	Located in the capital city. Some may say that Santo Antonio is the main port for traffic and a larger port. It is on the Principe part of the island and is the largest town. Limited information is available for which is the larger port. Sao Tome lacks the depth in the harbor for oil tankers to pass through[82].
Victoria	Seychelles	Located in the capital city.
Banjul	The Gambia	Located in the capital city.
Nuka Alofa	Tonga	Located in the capital city.

Appendix A Footnotes:

1: Algeria, *Arab Sea Ports Federation*, 2023. https://arabseaports.com/algeria-ports/algier

2: 7 Major Ports of Algeria, *Orbits Hub*, October 31, 2023. https://orbitshub.com/7-major-ports-of-algeria/

3: A Closer Look at the Major Australian Ports, *Platinum Freight Management*, January 15, 2024. https://platinumfreight.com.au/blog/a-closer-look-at-the-major-australian-ports-and-their-significance/

4: Historical Trade Data FY 22: Port of Melbourne. *Melbourne Port Authority*. historical-trade-data_FY22.pdf

5: The Top 50 Container Ports, *World Shipping Council*, 2019. https://www.worldshipping.org/top-50-ports

6: What are the 10 Major Ports in Brazil? *Merchant Navy Info*. Ports In Brazil: 10 Major Ports (merchantnavyinfo.com)

7: International Cargo Seaport: Port of Santos, *Tera Logistics*, February 21, 2022. Port of Santos - International Cargo Seaport | Tera Logistics

8: (1) Ahmed, Zahra. 10 Major Ports in Canada, *Marine Insight*, May 22, 2023. 10 Major Ports In Canada (marineinsight.com)
9: 2023 Statistics Overview, *Port of Vancouver: Vancouver Fraser Port Authority*, March 22, 2024. Statistics-overview-2021-to-2023.pdf (portvancouver.com)
10: Zhao, et al., January 2013, Characteristics and ship traffic source identification of air pollutants in China's largest port, *Atmospheric Environment*, Volume 64, pages 277-286. Characteristics and ship traffic source identification of air pollutants in China's largest port - ScienceDirect
11: Throughput Statistics, Port of Rijeka Authority. Port Authority – Troughput statistics (first graph)
12: (2) Ahmed, Zahra. September 15, 2023. 7 Major Ports of Croatia, *Marine Insight*. 7 Major Ports Of Croatia (marineinsight.com)
13: (3) Ahmed, Zahra. November 23, 2022. 7 Major Ports of Egypt. *Marine Insight.* 7 Major Ports Of Egypt
14: November 2023 Monthly Statistical Report, *Alexandria Port Authority*. December 20, 2023. Slide 1 (apa.gov.eg) pg 7 and translated using google translate lens feature.
15: 2017. Helsinki is the number one general port for international freight traffic in Finland. *Finnish Ports Assocation*. Helsinki is the number one general port for international freight traffic in Finland. | Suomen Satamaliitto
16: 2021 Annual Report. Port of Helsinki. *Port of Helsinki*. Main port for foreign trade and travel - Port of Helsinki Annual Report 2021
17: April 2021. French ports & yards analytic overview. *ISEMAR*. Sectorstudie Maritiem en Havens Frankrijk
18: Hamburg, Your Port! Port of Hamburg – Gateway to the world. *Port of Hamburg*. https://www.hafen-hamburg.de/en/portofhamburg/port-of-hamburg/
19: (1) Mohit. May 7, 2021. 10 Major Ports in Germany, *Marine Insight*. https://www.marineinsight.com/know-more/10-major-ports-in-germany/
20: Ports of Genoa, Italy. *Ports of Genoa*. Ports of Genoa - Autorità di Sistema Portuale Mar Ligure Occidentale
21: (1) Joshi, Rishab. March 26, 2022. 7 Major Ports in Malaysia. *Marine Insight*. 7 Major Ports in Malaysia

22: Tanger Med Port Authority. Tanger Med. *Tanger Med Port Authority*. Tanger Med Port Authority

23: Half year reports. 2024. *Port of Rotterdam*. Half year reports | Port of Rotterdam

24: (4) Ahmed, Zahra. November 28, 2022. 5 Major Ports in New Zealand. *Marine Insight*. 5 Major Ports In New Zealand

25: Top 5 Major Ports in New Zealand: What You Need to Know. *Connecta by panco*. Top 5 Major Ports in New Zealand: What You Need to Know

26: 5 Major Ports in New Zealand. *Orbits Hub*. 5 Major Ports In New Zealand (Updated)

27: (1) Bhattacharjee, Shilavadra. May 30, 2022. 6 Major Ports in Nigeria. *Marine Insight*. 6 Major Ports in Nigeria

28: Lagos Port Complex. *Nigerian Ports Authority*. Lagos Port Complex – Nigerian Ports Authority

29: (5) Ahmed, Zahra. May 8, 2024. 5 Major Ports in Portland. *Marine Insight*. 5 Major Ports in Poland

30: Business in the Port. *Port Gdansk*. Business - Port Gdańsk

31: Busan Port Volume Trend. *Busan Port Authority*. Total Cargo Traffic Trend (Tonnage) - Port Operation Statistics - Busan Port Statistics - Public Communication - Busan Port Authority (used google translate to read the website)

32: Busan Port. *DFREIGHT*. Busan Port: A Perfect Guide - 2022

33: Larsson, Lars. February 7, 2021. Spain's Top 3 Ports in 2021. *The Business Year*. Spain's Top 3 Ports in 2021 - The Business Year

34: (1) Menon, Ajay. May 4, 2021. 15 Major Ports in Spain. *Marine Insight*. 15 Major Ports in Spain

35: (2) Joshi, Rishab. April 3, 2022. 7 Major Ports in Sweden. *Marine Insight*. 7 Major Ports in Sweden

36: Container. *Port of Gothenburg*. Scandinavia's biggest container port.

37: Ports of Syria. *The Arab Sea Ports Federation*. Ports of Syria

38: Mambra, Shamseer. March 12, 2022. 8 Major Ports of Taiwan. *Marine Insight*. 8 Major Ports of Taiwan

39: (1) Sinha, Saurabh. August 27, 2021. 6 Major Ports in Turkey. *Marine Insight*. 6 Major Ports in Turkey

40: Public-Private Partnerships Briefs Ukraine: Odessa Port. April 2015. *World Bank*. World Bank Document

41: (3) Joshi, Rishab. April 14, 2022. 5 Major Ports of Ukraine. *Marine Insight*. 5 Major Ports of Ukraine

42: (6) Ahmed, Zahra. May 7, 2024. 10 Major Ports in Mexico. *Marine Insight*. https://www.marineinsight.com/know-more/10-major-ports-in-mexico/

43: CBRE. December 13, 2022. 2022 Global Seaport Review: Manzanillo, Mexico. *CBRE*. https://www.cbre.com/insights/local-response/2022-global-seaport-review-manzanillo

44: Port Statistics. *Karachi Port Trust*. https://kpt.gov.pk/pages/21/port-statistics

45: (2) Sinha, Saurabh. September 24, 2021. 4 Major Ports in Panama. *Marine Insight*. https://www.marineinsight.com/know-more/4-major-ports-in-panama/

46: (2) Mohit. October 22, 2021. 10 Major Ports in Romania. *Marine Insight*. https://www.marineinsight.com/ports/10-major-ports-in-romania/

47: Annual Report. *Constantza Port*. https://www.portofconstantza.com/pn/page/np_statistici_port

48: TERA Logistics. May 30, 2022. International Cargo Seaport: Port of Colombo. *TERA Logistics International Seaport*. https://www.teralogistics.com/international-cargo-seaport-port-of-colombo/

49: Arcelor Mittal. October 25, 2023. Rodange crane rails in Sri Lanka's largest port. *Arcelor Mittal*. https://luxembourg.arcelormittal.com/en/news-and-media/news/rodange-crane-rails-in-sri-lanka-s-largest-port#:~:text=Colombo%20is%20the%20largest%20port,sea%20route%20in%20South%20Asia

50: International Trade Administration. February 1, 2024. Angola – Country Commercial Guide. *United States International Trade Administration*. https://www.trade.gov/country-commercial-guides/angola-marine-technologies-fisheries-and-sea-ports

51: The Port of Lunda is the main seaport of Angola and its most important logistics infrastructure. *The Port of Luanda*. https://www.portoluanda.co.ao/en/the-port-of-luanda/

52: IMF PortWatch. 2022. Country Monitor Brunei Darussalam. *IMF PortWatch*. https://portwatch.imf.org/pages/brn

53: Strategic Location of Muara Port. *Muara Port Company SDN BHD*. https://www.muaraportcompany.com.bn/strategic-location/

54: (7) Ahmed, Zahra. November 24, 2022. 7 Major Ports in Burma. *Marine Insight*. https://www.marineinsight.com/know-more/ports-in-burma/

55: Deep Sea Ports. *Myanmar Port Authority*. https://www.mpa.gov.mm/deep-sea-ports/

56: Matadi (Democratic Republic of the Congo). *ShipNext The Shipping Platform*. https://shipnext.com/port/matadi-cdmat-cod#:~:text=Traffic%20figures%3A%20Approx%20350%20vessels%20visit%20the%20port,is%20175%2C000TEU%20and%20350%2C000%20tonnes%20of%20general%20cargo.

57: (8) Ahmed, Zahra. January 4, 2024. 9 Major Ports of Cyprus. *Marine Insight*. https://www.marineinsight.com/know-more/major-ports-of-cyprus/

58: Ports. *Cyprus Shipping Association*. https://www.csa-cy.org/article/ports

59: (4) Joshi, Rishab. May 17, 2022. 8 Major Ports in Ecuador. *Marine Insight*. https://www.marineinsight.com/know-more/8-major-ports-in-ecuador/

60: August 26, 2013. Fiji Maritime Transport: Suva and Lautoka Ports. *Asian Development Bank*. https://www.adb.org/features/fijis-ports-open-wider-world-report-card

61: (9) Ahmed, Zahra. October 12, 2022. 7 Major Ports in Fiji. Marine Insight. https://www.marineinsight.com/know-more/7-major-ports-in-fiji/

62: Guatemala (GTGUA). *Seabay Logistics*. https://www.seabaycargo.com/seaport/detail/Guatemala_Guatemala_GTGUA.html

63: Khant, Radhika. December 23, 2021. 5 Major Ports in Guatemala. *Marine Insight*. https://www.marineinsight.com/know-more/5-major-ports-in-guatemala/

64: Mambra, Shamseer. February 26, 2022. 6 Major Ports of Madagascar. *Marine Insight*. https://www.marineinsight.com/know-more/6-major-ports-of-madagascar/

65: Africa Ports. *Toamasina Port*. https://africaports.co.za/toamasina/

66: Southern Africa – Port Information: Port of Walvis Bay, Nambia. *LBH Group Walvis Bay*. https://www.lbhmozambique.com/wp-content/uploads/2019/03/LBH-WB_WalvisBay_PortInfo.pdf

67: Welcome to the Port of Walvis Bay. *Namport*. https://www.namport.com.na/ports/welcome-to-the-port-of-walvis-bay/522/

68: The Port of Noumea, a source of wealth for New Caledonia. *Choose New Caledonia!*. The Port of Nouméa, a source of wealth for New Caledonia | choosenewcaledoniea

69: 2.1.1 Nicaragua Port of Corinto. *Logistics Cluster LCA*. https://lca.logcluster.org/211-nicaragua-port-corinto

70: (3) Sinha, Saurabh. August 25, 2022. 6 Major Ports in Nicaragua. *Marine Insight*. https://www.marineinsight.com/know-more/6-major-ports-in-nicaragua/

71: Castreis (Saint Lucia). *ShipNext The Shipping Platform*. https://shipnext.com/port/castries-lccas-lca

72: Solomon Port Authority. 2020. Solomon Ports Annual Report 2019-2020. *Solomon Ports Authority*. https://www.sipa.com.sb/media/1797/sipa-2019-2020-web.pdf

73: Port Codes Mutsamudu (KMMUT). *Seabay Cargo*. https://www.seabaycargo.com/seaport/detail/Mutsamudu_Comoros_KMMUT.html

74: (2) Menon, Ajay. October 16, 2021. 3 Major Ports of El Salvador. *Marine Insight*. https://www.marineinsight.com/know-more/3-major-ports-of-el-salvador/

75: Ports – El Salvador. *Refrat Energy Solutions*. https://refrat-oil.com/en/ports-of-el-salvador-2/

76: (5) Joshi, Rishab. June 1, 2022. 7 Major Ports in Costa Rica. *Marine Insight*. https://www.marineinsight.com/know-more/ports-in-costa-rica/

77: (6) Joshi, Rishab. April 7, 2022. 5 Major Ports in Colombia. *Marine Insight*. https://www.marineinsight.com/know-more/5-major-ports-in-colombia/

78: Montenegro Marinas. *Visit Montegnegro*. https://www.visit-montenegro.com/transport/transportation-ports-marinas/#:~:text=The%20port%20of%20Bar%20is,of%20Montenegro%20with%20all%20world.

79: (4) Sinha, Saurabh. August 23, 2021. 5 Major Ports in Montenegro. *Marine Insight*. https://www.marineinsight.com/know-more/5-major-ports-in-montenegro/

80: Al Aqaba port. *The Arab Sea Ports Federation*. https://arabseaports.com/al-aqaba-port

81: Roseau (Dominica). *ShipNext The Shipping Platform*. Roseau DMRSU Details: Departures, Expected Arrivals and Roseau (Dominica) Calls | Shipnext

82: Sao Tome Island (STTMS) Port Codes. *Seabay Logistics*. STTMS - Sao Tome Island Port Code - Seabay Logistics

83: (7) Joshi, Rishab. May 13, 2022. 6 Major Ports in Iran. *Marine Insight*. 6 Major Ports in Iran

84: (2) Bhattacharjee, Shilavadra. April 19, 2022. 6 Major Ports of Israel. *Marine Insight*. 6 Major Ports of Israel

85: Pointe Noire (Republic of the Congo). *ShipNext The Shipping Platform*. https://shipnext.com/port/582846051c912f0ebcb63d16

Appendix B - Percentage Change in Imported Calories under Counterfactual Scenarios

Appendix Table B.1 Ranking of countries percentage change in imported calories when the Panama Canal is not a part of maritime trade routes

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
1	SLV	El Salvador	-62.004597
2	ECU	Ecuador	-40.314852
3	PER	Peru	-32.807953
4	WSM	Samoa	-31.640539
5	PYF	French Polynesia	-29.765895
6	TON	Tonga	-24.977358
7	AUS	Australia	-20.244258
8	FJI	Fiji	-11.857602
9	NZL	New Zealand	-7.1144794
10	MAC	China, Macao SAR	-6.5897183
11	HKG	China, Hong Kong SAR	-5.5670672
12	CHL	Chile	-5.5191005
13	SLB	Solomon Islands	-4.4646447
14	PNG	Papua New Guinea	-3.9600865
15	BRN	Brunei Darussalam	-2.7265865
16	TWN	China, Taiwan Province of	-2.5117836
17	JPN	Japan	-2.0690065
18	PHL	Philippines	-1.9280524
19	KOR	Republic of Korea	-1.673181
20	CHN	China, mainland	-0.4568895
21	VNM	Viet Nam	-0.3748688
22	USA	United States of America	-0.2952078
23	NCL	New Caledonia	-0.2098054
24	KHM	Cambodia	-0.1461588

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
25	THA	Thailand	-0.1362257
26	GTM	Guatemala	-0.0876245
27	HND	Honduras	-0.0865849
28	CRI	Costa Rica	-0.0765944
29	VEN	Venezuela (Bolivarian Republic of)	-0.0339826
30	DOM	Dominican Republic	-0.0163422
31	VCT	Saint Vincent and the Grenadines	-0.0085518
32	BHS	Bahamas	-0.0035049
33	NIC	Nicaragua	-0.0031096
34	ISL	Iceland	-0.002217
35	ESP	Spain	-0.0016759
36	FRA	France	-0.0012381
37	ITA	Italy	-0.0011876
38	MAR	Morocco	-0.0010277
39	HRV	Croatia	-0.0008848
40	BLZ	Belize	-0.0008076
41	NOR	Norway	-0.0006798
42	LCA	Saint Lucia	-0.0006045
43	NLD	Netherlands (Kingdom of the)	-0.0005675
44	DMA	Dominica	-0.0005478
45	ARE	United Arab Emirates	-0.0005011
46	DEU	Germany	-0.00049
47	ALB	Albania	-0.0004353
48	SWE	Sweden	-0.000402
49	GRD	Grenada	-0.0003579
50	JAM	Jamaica	-0.0003437
51	BIH	Bosnia and Herzegovina	-0.0003412
52	TTO	Trinidad and Tobago	-0.0003102
53	ATG	Antigua and Barbuda	-0.0002634

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
54	GBR	United Kingdom of Great Britain and Northern Ireland	-0.0002633
55	GUY	Guyana	-0.0002629
56	TUR	Türkiye	-0.0002603
57	PRT	Portugal	-0.0002391
58	SUR	Suriname	-0.0002236
59	DZA	Algeria	-0.0002232
60	BHR	Bahrain	-0.0002226
61	KNA	Saint Kitts and Nevis	-0.0002196
62	LBN	Lebanon	-0.000195
63	KWT	Kuwait	-0.0001485
64	JOR	Jordan	-0.0001414
65	MNE	Montenegro	-0.0001411
66	IRL	Ireland	-0.0001319
67	DNK	Denmark	-0.0001017
68	BRB	Barbados	-9.42E-05
69	RUS	Russian Federation	-6.61E-05
70	BEL	Belgium	-6.06E-05
71	FIN	Finland	-5.70E-05
72	UKR	Ukraine	-4.99E-05
73	EGY	Egypt	-4.16E-05
74	MDV	Maldives	-4.05E-05
75	GRC	Greece	-3.16E-05
76	ROU	Romania	-1.67E-05
77	POL	Poland	-1.44E-05
78	GEO	Georgia	-9.42E-06
79	BGR	Bulgaria	-2.61E-06
80	CPV	Cabo Verde	-7.24E-07
81	AGO	Angola	0

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
82	ARG	Argentina	0
83	BEN	Benin	0
84	BGD	Bangladesh	0
85	BRA	Brazil	0
86	CAN	Canada	0
87	CIV	Côte d'Ivoire	0
88	CMR	Cameroon	0
89	COD	Democratic Republic of the Congo	0
90	COG	Congo	0
91	COK	Cook Islands	0
92	COL	Colombia	0
93	COM	Comoros	0
94	CUB	Cuba	0
95	CYP	Cyprus	0
96	DJI	Djibouti	0
97	EST	Estonia	0
98	FRO	Faroe Islands	0
99	GAB	Gabon	0
100	GHA	Ghana	0
101	GIN	Guinea	0
102	GMB	Gambia	0
103	IDN	Indonesia	0
104	IND	India	0
105	IRN	Iran (Islamic Republic of)	0
106	ISR	Israel	0
107	KEN	Kenya	0
108	LBY	Libya	0
109	LKA	Sri Lanka	0
110	LTU	Lithuania	0

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
111	LVA	Latvia	0
112	MDG	Madagascar	0
113	MEX	Mexico	0
114	MLT	Malta	0
115	MMR	Myanmar	0
116	MOZ	Mozambique	0
117	MRT	Mauritania	0
118	MUS	Mauritius	0
119	MYS	Malaysia	0
120	NAM	Namibia	0
121	NGA	Nigeria	0
122	OMN	Oman	0
123	PAK	Pakistan	0
124	PAN	Panama	0
125	PRY	Paraguay	0
126	QAT	Qatar	0
127	SAU	Saudi Arabia	0
128	SEN	Senegal	0
129	SGP	Singapore	0
130	SLE	Sierra Leone	0
131	STP	Sao Tome and Principe	0
132	SVN	Slovenia	0
133	SYC	Seychelles	0
134	SYR	Syrian Arab Republic	0
135	TGO	Togo	0
136	TUN	Tunisia	0
137	TZA	United Republic of Tanzania	0
138	URY	Uruguay	0
139	YEM	Yemen	0

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
140	ZAF	South Africa	0

Appendix Table B.2 Ranking of countries percentage change in imported calories when the Suez Canal is not a part of maritime trade routes

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
1	JOR	Jordan	-81.35757742
2	DJI	Djibouti	-74.54042866
3	YEM	Yemen	-70.98525226
4	IRN	Iran (Islamic Republic of)	-54.09785942
5	ARE	United Arab Emirates	-50.68998264
6	OMN	Oman	-45.21069384
7	LKA	Sri Lanka	-44.12833268
8	QAT	Qatar	-44.08854727
9	SAU	Saudi Arabia	-38.12674888
10	IND	India	-36.82728572
11	KWT	Kuwait	-35.4830565
12	KEN	Kenya	-34.4823669
13	TZA	United Republic of Tanzania	-30.84087496
14	BHR	Bahrain	-30.75609651
15	SYC	Seychelles	-28.48859615
16	PAK	Pakistan	-26.64340328
17	MDG	Madagascar	-23.67508487
18	MMR	Myanmar	-19.31959805
19	BGD	Bangladesh	-17.95987558
20	COM	Comoros	-16.8293858
21	MOZ	Mozambique	-15.46224419
22	MDV	Maldives	-13.59696207
23	MYS	Malaysia	-12.93424323
24	IDN	Indonesia	-10.79001041
25	THA	Thailand	-8.945831692

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
26	TWN	China, Taiwan Province of	-7.805579441
27	VNM	Viet Nam	-7.368810165
28	PHL	Philippines	-5.741651273
29	KHM	Cambodia	-3.99354494
30	MUS	Mauritius	-3.246421523
31	JPN	Japan	-2.735816977
32	ZAF	South Africa	-2.695985013
33	KOR	Republic of Korea	-2.043374349
34	NCL	New Caledonia	-1.939042126
35	SGP	Singapore	-1.890768458
36	NZL	New Zealand	-0.816745937
37	CHN	China, mainland	-0.715306375
38	ISR	Israel	-0.444602875
39	EGY	Egypt	-0.430678641
40	LBN	Lebanon	-0.367628847
41	MAC	China, Macao SAR	-0.345998826
42	BRN	Brunei Darussalam	-0.106043047
43	GMB	Gambia	-0.101518274
44	BIH	Bosnia and Herzegovina	-0.091887162
45	MNE	Montenegro	-0.078448352
46	DZA	Algeria	-0.076274888
47	TUN	Tunisia	-0.064505568
48	HKG	China, Hong Kong SAR	-0.064193137
49	ITA	Italy	-0.052671365
50	AUS	Australia	-0.046032271
51	CYP	Cyprus	-0.044438278
52	ISL	Iceland	-0.04316675
53	SLE	Sierra Leone	-0.043045595
54	TUR	Türkiye	-0.042873142

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
55	SYR	Syrian Arab Republic	-0.041561264
56	ESP	Spain	-0.034505557
57	GIN	Guinea	-0.033942823
58	MAR	Morocco	-0.033280123
59	HRV	Croatia	-0.029974985
60	LBY	Libya	-0.026493518
61	NOR	Norway	-0.020571765
62	MLT	Malta	-0.018068585
63	MRT	Mauritania	-0.014489956
64	GBR	United Kingdom of Great Britain and Northern Ireland	-0.013034199
65	ALB	Albania	-0.012751575
66	CAN	Canada	-0.011908506
67	SEN	Senegal	-0.010800172
68	IRL	Ireland	-0.009476532
69	USA	United States of America	-0.009226344
70	FRA	France	-0.008495926
71	PRT	Portugal	-0.00719588
72	UKR	Ukraine	-0.007072378
73	TTO	Trinidad and Tobago	-0.005709852
74	DOM	Dominican Republic	-0.005209528
75	NLD	Netherlands (Kingdom of the)	-0.005176168
76	BRB	Barbados	-0.005170716
77	JAM	Jamaica	-0.003917197
78	DEU	Germany	-0.003655925
79	SWE	Sweden	-0.00271946
80	GEO	Georgia	-0.002653866
81	VCT	Saint Vincent and the Grenadines	-0.002294054
82	BLZ	Belize	-0.001723385

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
83	COL	Colombia	-0.001654661
84	GTM	Guatemala	-0.001638249
85	VEN	Venezuela (Bolivarian Republic of)	-0.001429396
86	ECU	Ecuador	-0.001397559
87	CPV	Cabo Verde	-0.001290052
88	SUR	Suriname	-0.000975713
89	BEL	Belgium	-0.000822669
90	SLV	El Salvador	-0.000775811
91	RUS	Russian Federation	-0.000605844
92	PAN	Panama	-0.000389301
93	GRC	Greece	-0.000383995
94	MEX	Mexico	-0.000331288
95	FIN	Finland	-0.000325576
96	CIV	Côte d'Ivoire	-0.0002889
97	DNK	Denmark	-0.000257355
98	SVN	Slovenia	-0.000165734
99	LVA	Latvia	-0.000154217
100	ATG	Antigua and Barbuda	-0.000144727
101	PNG	Papua New Guinea	-0.000138491
102	BGR	Bulgaria	-7.62124E-05
103	GHA	Ghana	-5.34813E-05
104	ROU	Romania	-4.50913E-05
105	AGO	Angola	-3.48644E-05
106	BHS	Bahamas	-2.86493E-05
107	POL	Poland	-4.49377E-06
108	DMA	Dominica	-2.99271E-06
109	EST	Estonia	-1.98453E-06
110	GUY	Guyana	-1.49086E-06
111	LTU	Lithuania	-1.42743E-06

Rank	R_ISO	Reporter (importing) Countries	Imported calories (% change)
112	ARG	Argentina	0
113	BEN	Benin	0
114	BRA	Brazil	0
115	CHL	Chile	0
116	CMR	Cameroon	0
117	COD	Democratic Republic of the Congo	0
118	COG	Congo	0
119	COK	Cook Islands	0
120	CRI	Costa Rica	0
121	CUB	Cuba	0
122	FJI	Fiji	0
123	FRO	Faroe Islands	0
124	GAB	Gabon	0
125	GRD	Grenada	0
126	HND	Honduras	0
127	KNA	Saint Kitts and Nevis	0
128	LCA	Saint Lucia	0
129	NAM	Namibia	0
130	NGA	Nigeria	0
131	NIC	Nicaragua	0
132	PER	Peru	0
133	PRY	Paraguay	0
134	PYF	French Polynesia	0
135	SLB	Solomon Islands	0
136	STP	Sao Tome and Principe	0
137	TGO	Togo	0
138	TON	Tonga	0
139	URY	Uruguay	0
140	WSM	Samoa	0

Appendix Table B.3 Ranking of countries percentage change in imported calories when the Malacca Strait is not a part of maritime trade routes

Rank	R_ISO	Reporter (importing) Countries	Imported Calories (% change)
1	MYS	Malaysia	-19.6038
2	BGD	Bangladesh	-7.0319
3	MMR	Myanmar	-5.31943
4	SGP	Singapore	-3.29414
5	THA	Thailand	-2.47302
6	VNM	Viet Nam	-1.71828
7	TWN	China, Taiwan Province of	-1.20487
8	BRN	Brunei Darussalam	-0.99829
9	PHL	Philippines	-0.89747
10	KHM	Cambodia	-0.89295
11	JPN	Japan	-0.4402
12	KOR	Republic of Korea	-0.32431
13	HKG	China, Hong Kong SAR	-0.2943
14	MDV	Maldives	-0.20462
15	CHN	China, mainland	-0.19113
16	IDN	Indonesia	-0.15617
17	MAC	China, Macao SAR	-0.09803
18	LKA	Sri Lanka	-0.06531
19	IND	India	-0.05074
20	PAK	Pakistan	-0.03688
21	SYC	Seychelles	-0.02149
22	KWT	Kuwait	-0.01609
23	BHR	Bahrain	-0.01578
24	SAU	Saudi Arabia	-0.01244
25	ARE	United Arab Emirates	-0.01084
26	QAT	Qatar	-0.00901
27	IRN	Iran (Islamic Republic of)	-0.00901

Rank	R_ISO	Reporter (importing) Countries	Imported Calories (% change)
28	OMN	Oman	-0.00649
29	YEM	Yemen	-0.00332
30	ISL	Iceland	-0.0027
31	KEN	Kenya	-0.00259
32	BIH	Bosnia and Herzegovina	-0.00217
33	MNE	Montenegro	-0.002
34	TZA	United Republic of Tanzania	-0.00171
35	GMB	Gambia	-0.00132
36	EGY	Egypt	-0.00113
37	ISR	Israel	-0.00093
38	SEN	Senegal	-0.00067
39	LBN	Lebanon	-0.00065
40	MRT	Mauritania	-0.00057
41	SLB	Solomon Islands	-0.00051
42	DZA	Algeria	-0.0005
43	NOR	Norway	-0.00047
44	SYR	Syrian Arab Republic	-0.00046
45	MDG	Madagascar	-0.00042
46	BRB	Barbados	-0.0004
47	PNG	Papua New Guinea	-0.00037
48	NZL	New Zealand	-0.00029
49	HRV	Croatia	-0.00026
50	CPV	Cabo Verde	-0.00024
51	JOR	Jordan	-0.00023
52	ALB	Albania	-0.00019
53	ESP	Spain	-0.00018
54	DOM	Dominican Republic	-0.00015
55	LBY	Libya	-0.00015
56	FRA	France	-0.00011

Rank	R_ISO	Reporter (importing) Countries	Imported Calories (% change)
57	SWE	Sweden	-0.00011
58	TUR	Türkiye	-0.0001
59	COM	Comoros	-9E-05
60	ITA	Italy	-7.8E-05
61	IRL	Ireland	-7.2E-05
62	NLD	Netherlands (Kingdom of the)	-7.1E-05
63	CYP	Cyprus	-6.9E-05
64	GBR	United Kingdom of Great Britain and Northern Ireland	-6.8E-05
65	MAR	Morocco	-6.3E-05
66	FJI	Fiji	-6.2E-05
67	TTO	Trinidad and Tobago	-5.4E-05
68	CAN	Canada	-5.3E-05
69	VCT	Saint Vincent and the Grenadines	-5E-05
70	DEU	Germany	-4.7E-05
71	ATG	Antigua and Barbuda	-4.6E-05
72	PRT	Portugal	-4.1E-05
73	SVN	Slovenia	-3.2E-05
74	BHS	Bahamas	-2.9E-05
75	DNK	Denmark	-2E-05
76	VEN	Venezuela (Bolivarian Republic of)	-1.7E-05
77	TUN	Tunisia	-1.2E-05
78	GEO	Georgia	-9.7E-06
79	BEL	Belgium	-8.5E-06
80	FIN	Finland	-7.6E-06
81	MLT	Malta	-6.5E-06
82	GUY	Guyana	-1.5E-06
83	MEX	Mexico	-9.5E-07
84	SUR	Suriname	-8.2E-07

Rank	R_ISO	Reporter (importing) Countries	Imported Calories (% change)
85	LVA	Latvia	-7.2E-07
86	POL	Poland	-6.7E-07
87	ROU	Romania	-6.7E-07
88	EST	Estonia	-5E-07
89	LTU	Lithuania	-3.5E-07
90	BGR	Bulgaria	-2.8E-07
91	AGO	Angola	0
92	ARG	Argentina	0
93	AUS	Australia	0
94	BEN	Benin	0
95	BLZ	Belize	0
96	BRA	Brazil	0
97	CHL	Chile	0
98	CIV	Côte d'Ivoire	0
99	CMR	Cameroon	0
100	COD	Democratic Republic of the Congo	0
101	COG	Congo	0
102	COK	Cook Islands	0
103	COL	Colombia	0
104	CRI	Costa Rica	0
105	CUB	Cuba	0
106	DJI	Djibouti	0
107	DMA	Dominica	0
108	ECU	Ecuador	0
109	FRO	Faroe Islands	0
110	GAB	Gabon	0
111	GHA	Ghana	0
112	GIN	Guinea	0
113	GRC	Greece	0

Rank	R_ISO	Reporter (importing) Countries	Imported Calories (% change)
114	GRD	Grenada	0
115	GTM	Guatemala	0
116	HND	Honduras	0
117	JAM	Jamaica	0
118	KNA	Saint Kitts and Nevis	0
119	LCA	Saint Lucia	0
120	MOZ	Mozambique	0
121	MUS	Mauritius	0
122	NAM	Namibia	0
123	NCL	New Caledonia	0
124	NGA	Nigeria	0
125	NIC	Nicaragua	0
126	PAN	Panama	0
127	PER	Peru	0
128	PRY	Paraguay	0
129	PYF	French Polynesia	0
130	RUS	Russian Federation	0
131	SLE	Sierra Leone	0
132	SLV	El Salvador	0
133	STP	Sao Tome and Principe	0
134	TGO	Togo	0
135	TON	Tonga	0
136	UKR	Ukraine	0
137	URY	Uruguay	0
138	USA	United States of America	0
139	WSM	Samoa	0
140	ZAF	South Africa	0