ERASMUS UNIVERSITY ROTTERDAM

Erasmus School of Economics

Bachelor Thesis Economics and Business Economics

The Effects of Natural Calamities and Geopolitical Instabilities on Maritime Choke Points: The Consequences of the Panama and Suez Canal Disruptions on Bilateral Trade Flows.

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Abstract

Geopolitical instabilities and natural disasters in primary maritime choke points, such as the Panama and Suez Canal, significantly disrupt global shipping routes by impacting trade flows. This study examines the economic implications of rerouting vessels through alternative choke points. Specifically, the alternative routes through the Cape of Good Hope, instead of the Suez Canal, and those through the Strait of Magellan and Drake Passage, instead of the Panama Canal, will be analyzed. These two waterways are the main object of study because they are currently facing disruptions: while the Suez Canal has seen an increase in piracy attacks in the past few months, the Panama Canal has been facing droughts; these two events reduced the number of daily vessels crossing the two choke points and forced shipping companies to opt for alternative routes. By using an empirical analysis and an augmented gravity model, the research investigates how increased transportation costs and longer sea distances affect bilateral trade flows between trading partners across different areas of the world. Results indicate that, while alternative routes can mitigate the effects of disruptions in primary choke points, they incur substantial additional costs and are associated with a lower bilateral trade flow between Asian and European countries. The findings of this study help research so that stakeholders in the maritime field, such as governments, policy-makers, port authorities, and shipping companies cooperate to prevent and mitigate the negative effects of disruptions in major choke points.

1. Introduction

Maritime shipping is crucial for global commerce, accounting for about 60% of the world's trade by value and 90% by volume (UNCTAD, 2022). This trade mainly relies on sea routes through marine choke points, which are constricted passages between land areas that separate oceans and seas. These waterways can be recognized by three characteristics: the passages should be narrow and capable of being closed to commercial and military shipping, there should be no optional readily available maritime route to utilize in the event of closure and they should be of considerable significance to at least a few states (Alexander, 1992). There are over 250 international straits that connect two parts of high seas or an exclusive economic zone. However, approximately 90% are important for commercial shipping and could qualify as choke points. Alexander (1992) defines "primary" choke points as waterways that fulfill all the three characteristics mentioned, while "secondary" choke points lack at least one of the criteria. Having taken this into account, there are eight primary choke points in the oceans: the Gibraltar Strait, Bab el-Mandeb Strait, Hormuz Strait, Turkish Straits, Cape of Good Hope, Strait of Malacca, and Suez and Panama Canals.

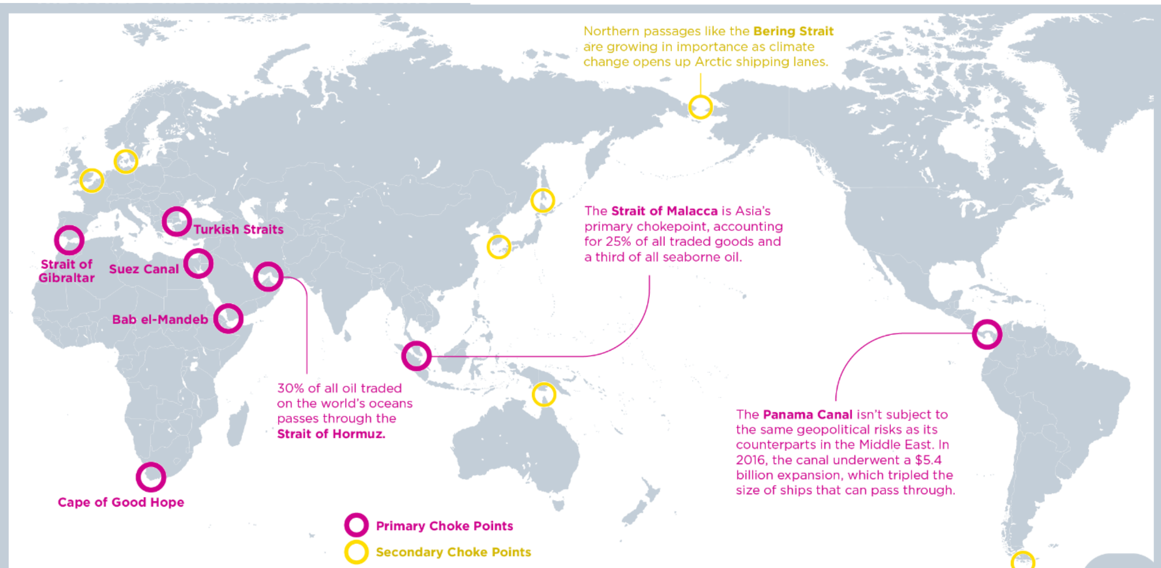

Figure 1. The World's Key Maritime Choke Points. Source: Ang C. (2021). Copyright 2021 by Visual Capitalist with permission.

This study aims to answer the following research question:

How do geopolitical instability and natural disasters in the primary choke points of Panama and Suez Canal influence bilateral shipping trade?

Bilateral trade is defined as the exchange of goods between two nations promoting trade and investment, in order to reduce or eliminate tariffs and other types of trade barriers. The aim of expanding trade between two countries stands in increasing the economic growth of their markets. Furthermore, bilateral trade agreements standardize regulations, labor standards, and environmental protection (Kagan, 2020).

To answer the research question, the paper will firstly analyze the historical developments and events that the choke points have faced. Hence, the following sub-question will be answered in chapter 2.1:

1. *What are the historical developments and current operational characteristics of the Panama and Suez Canal?*

Given the nature of the straits, they pose two main risks (Ang, 2021):

-Structural risks: since the choke points are narrow or depend on natural resources (such as the Panama Canal), ship crashes or natural disasters can lead to financial losses and delays.

-Geopolitical risks: because of the high traffic, the passages are vulnerable to blockades or disruptions during periods of political instability.

Chapter 2.3 of this study aims to assess the risks of choke points and answer the following sub-question:

2. *What are the key risks and uncertainties associated with rerouting maritime traffic through primary choke points, and in what way have these risks been affecting shipping operations and trade flows?*

The global supply chain is now being disrupted by two events:

On the 19th of October 2023, the Iranian Houthi movement in Yemen launched missiles and drones at Israel, demanding a retreat from the Gaza Strip. Since then, the Red Sea crisis began and the Houthis have started targeting vessels, particularly in the Bab el-Mandeb Strait, which is the main gateway to the Suez Canal in Egypt (Partington, 2024). Despite the Houthis claiming they would target only ships associated with Israel, the USA or Great Britain, there have been reports of indiscriminate attacks on ships of other nations (Congressional Research Service, 2024). Furthermore, the attacks also focused commercial vessels, causing damages and fatalities (Scarr et al., 2024). Despite the deployment of armed navies from the US, UK, Australia, Bahrain, Canada and the Netherlands, the attacks did not stop (The White House, 2024). This situation exposed companies not only to higher operational risks but also raised insurance premia. The main shipping carriers, including Hapag-Lloyd, Maersk, MSC, COSCO-OOCL, and CMA-CMG, announced rerouting of their vessel through Cape of Good Hope, to avoid the Red Sea and the Suez Canal (Shipsgo, 2023).

On the other side of the globe, the country of Panama has been affected by a severe drought since 2023, causing issues in the global supply chain (Canal de Panamá, 2023). The Canal uses a system of locks with two lanes, and it operates as an elevator, raising the ships from sea level to the level of Gatun Lake: the water needed for raising and lowering the vessels is obtained directly from the lake (Embassy of Panama, 2024). In 2022, an average of 39 vessels transited the Panama Canal daily (Safety4Sea, 2024). The Panama Canal Authority reduced the daily transit capacity to 18 passages a day in February 2024 (Panama Canal Authority, 2023) and then increased it to 32 in April 2024 (Safety4Sea, 2024), due to the drought conditions. Optional routes usually go from the Suez Canal, the Cape of Good Hope, the Strait of Magellan, and the Drake Passage. However, due to the Red Sea crisis, companies are avoiding the Suez Canal (Dierker et al., 2024).

Hence, Chapter 3.1 of this study will provide the answer for the following sub-question:

3. *How do changes in transport costs due to rerouting through the Cape of Good Hope, the Strait of Magellan, and the Drake Passage impact overall maritime shipping costs for different types of vessels?*

A gravity model will be performed, aiming to analyze the change in trade flow following the shock in transportation costs caused by rerouting a voyage through the Strait of Magellan or the Drake Passage and the Cape of Good Hope, instead of respectively the Panama and Suez Canal for American, Asian and European countries.

The gravity model, originally proposed by Tinbergen, predicts bilateral trade flows based on the economic sizes (GDP) of the trading partners and the distance between them. It will be augmented to include transportation costs and sea distances, which act as friction to trade. The average transportation costs for crude oil tankers, dry bulk carriers, and container ships will be estimated, and the gravity model will be performed on the entire trade flow of selected countries.

The following sub question will then be answered in Chapter 4.2:

4. *What are the specific effects of increased transport distances and costs on bilateral trade flows between major trading partners in different areas of the worlds, specifically focusing on the alternative routes affected by the Panama and Suez Canal closures?*

This study is socially relevant as the economic impact of a change in trade flow can affect the global prices of goods and the availability of many products. Furthermore, increasing shipping prices can have an impact on the economies and livelihoods around the globe. The extreme droughts in Panama highlight the increasing need to mitigate climate change consequences and raise attention to sustainability issues. The repercussions of these events need to be empirically studied in order to inform policymakers, governments, and stakeholders involved in the global supply chain on how to prevent and mitigate welfare losses.

After the recent expansion of the Panama Canal and Suez Canal, most research has been done to understand how trade flow has been positively influenced by the increasing number of ships passing through the choke points (Pagano et al., 2012; Mostafa, 2004). However, not much research has been done to understand the negative effects of disruptions in these choke points, resulting in a lack of scientific literature for policy-makers and companies. This study is scientifically relevant as it helps to understand the consequences of the recent disruption of the Suez and Panama Canal and fills the gap in the scientific literature on maritime trade.

The results will be discussed, and it will be possible to estimate the impact of the higher transportation costs and sea distances caused by the disruptions in the primary choke points of Panama and Suez.

2. Theoretical Framework

2.1 The Impact of the Panama and Suez Canals on Shipping Trade

The following chapter will provide an analysis to discuss the first sub-question “What are the historical developments and current operational characteristics of the Panama and Suez Canal?” and will present the main historical events and current characteristics of the Panama and Suez Canal.

2.1.1 The Panama Canal

The Panama Canal was built over 100 years ago and was originally controlled by the U.S; today is currently managed by the Panama Canal Authority. It has been completed in 1914 and connects the Atlantic and Pacific Oceans through the Isthmus of Panama having a strategic importance rivaling the Suez Canal. The Canal features a series of locks to lift ships across varying elevations: continuous maintenance is fundamental due to challenges such as heavy rainfalls and sedimentation. The construction was a monumental engineering achievement that required the support of the U.S., which saw the Panama Canal as a tool to enhance its share of global trade markets. Over the years, the canal has faced many engineering improvements, such as the construction of dams, highways, and bridges. However, the most notable expansion has been the addition of a third set of locks, completed in 2016 (Padelford et al., 2024). Before this expansion, only Panamax-sized vessels (294 meters in length and 32 in width) could go through the locks. However, the recent upgrade enables post-Panamax-sized vessels (366 meters in length and 49 in width) to cross the canal.

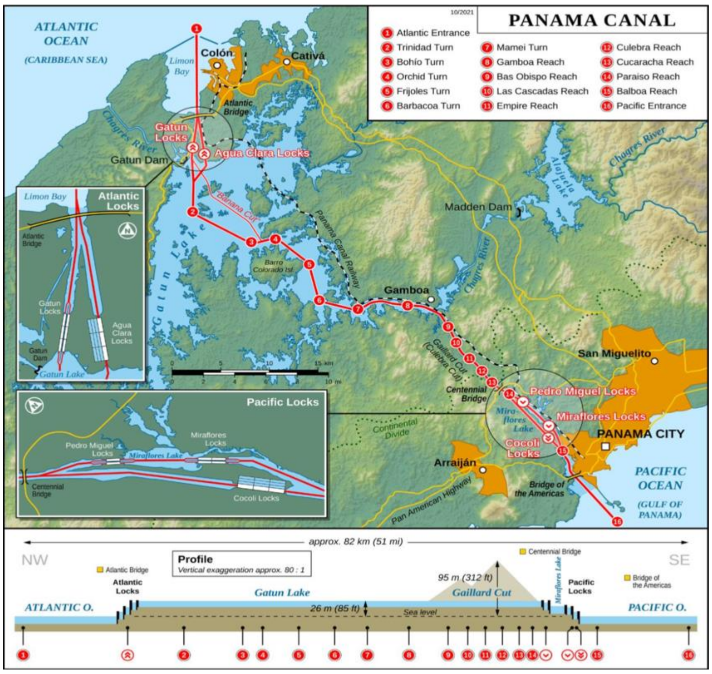

Figure 2. Map of the Panama Canal. Source: Thomas Römer/OpenStreetMap Data-Free to use under a CC BY-SA 2.0 License (Dimitrios, 2023).

Revenues from tolls in 2021 accounted for approximately 2$ billion, approximately 3% of Panama's GDP (IMF Western Hemisphere Dept, 2023). With a movement of roughly 270$ billion worth of cargo annually, the canal handles about 5% of global maritime trade and 40% of all US container traffic (Wallach, 2024). In 2023, despite the droughts, 14,080 vessels crossed the canal with an average of 39 ships per day. Between 2014 and 2022 the average transits per year were approximately 13,630 (Georgia Tech Panama, 2024). The expansion of the Canal did not enhance the number of yearly transits; however, it increased the tolls by allowing transit to larger vessels.

The transit of the Canal can usually be completed between 8-10 hours. However, the waiting time in line to cross the Canal is highly dependent on whether the shipping carrier has a reservation, the natural resources available and general congestion. According to the Panama Canal Authority, the average waiting time for non-booked vessels has increased to 9.3 days in the Northbound side, and to 10.5 days in the Southbound side, at the end of November 2023 (Bajic, 2023). The decreasing number of allowed passages per day increases congestion and waiting times for vessels, which may prefer to reroute to avoid the Canal tolls and the daily operational costs. Many different types of vessels cross the Canal each year; container ships have the largest share of net tonnage of goods shipped, followed by dry bulk carriers, liquefied petroleum gas tankers, vehicles carriers, and chemicals tankers. The principal commodity groups moved through the Canal are motor vehicles, petroleum products, grains, coal, and coke (Wallach, 2024).

2.1.2 The Suez Canal

The Suez Canal, operated by the Suez Canal Authority and owned by the Egyptian government, was opened in 1869; it connects the Mediterranean and Red Seas, serving as a key shipping waterway between Europe and regions around the Indian and Western Pacific Oceans. It stretches for 193km across the Isthmus of Suez in Egypt separating Africa from Asia. Despite various disruptions such as the Arab-Israeli conflict in 1967, over the years numerous progresses such as the widening, deepening, and addition of passing bays have been made. It was expanded in 2015 with a 9$ billion investment and has now a width of 312 meters for 35 kilometers, enabling the passage to post-Suezmax vessels.

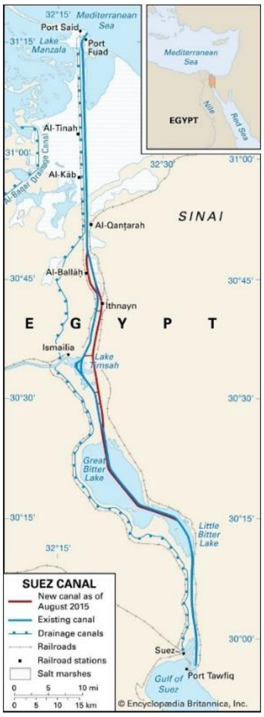

Figure 3. Map of the Suez Canal. Source: Encyclopædia Britannica (2024).

The canal plays a crucial role in global trade and its importance has shifted with changes in trade patterns, such as the rise of oil shipments from the Persian Gulf and the development of intermodal transportation. It has seen a decline in passenger traffic due an increasing air travel competition but remains essential for the transportation of various cargo. In 2021, the International Chamber of Shipping estimated that up to 3$ billion worth of cargo passed through the canal every day (Hincks, 2021), accounting for 12% of global shipping traffic and 30% of global shipping container traffic (Lane, 2024). Tolls generated a record of $9.4 billion during the past year, accounting for 2.3% of Egyptian GDP in 2023 (UNCTAD, 2024). About 50 ships a day pass through the canal, mainly split between container ships, tankers, and dry bulk carriers. Estimates show how this choke point enables the transfer of 7-10% of the world's oil with over 1 million barrels traded every day, and 8% of the world's liquefied natural gas (LNG) (New Zealand Embassy, 2021).

2.2 Alternative Routes

2.2.1 The Strait of Magellan and the Drake Passage

The Strait of Magellan is a connecting channel for the Atlantic and Pacific oceans, located between the mainland tip of South America and Tierra del Fuego Island; it lies entirely within the Chilean territorial waters and stretches for 560km in length. The Strait served as an important sailing route before the construction of the Panama Canal shortening the Atlantic-Pacific passage. Today it remains an important passage for shipping, trade, and navigation (Cotter et al., 2024). The Strait of Magellan is very close to another important choke point, the Drake Passage, around Cape Horn. Both passages represent very unique and challenging routes due to the strong Antarctician tidal currents, small islands, fog, and icing. Despite circumnavigating Cape Horn and the Drake Passage is described as more challenging than the Strait of Magellan (iMariners, 2023), the narrowness and currents in the Strait of Magellan require vessels to be piloted through the whole passage, with fees from 3,800-20,000 USD depending on the size of the vessel. While navigation hazards usually restrain shipping companies from sailing the passages, the associated risks of crossing the Suez Canal and the delays and tolls resulting from crossing the Panama Canal are suggesting companies to reroute their vessels (Dierker et al, 2024).

2.2.2 The Cape of Good Hope

The Cape of Good Hope, located at the southern tip of the Cape Peninsula in South Africa, holds a significant place in maritime history. It was initially used as a route from Europe to India and was originally named "Cape of Storms", due to the harsh weather conditions during the voyages; it was later renamed Cape of Good Hope, symbolizing the hope and potential of finding a trade passage to the East. Geographically, the Cape of Good Hope is found at the meeting point between the warm currents of Mozambique and the Antarctic waters: the convergence creates challenging maritime conditions, with strong winds and rough seas (Britannica, 2024). This route also presents major concerns regarding piracy: Somalian-based pirates are the reason for hundreds of attacks on vulnerable vessels. Despite these concerns, the Cape of Good Hope has been considered by the major shipping companies a less risky route, compared to the one crossing the Suez Canal (Shipsgo, 2023).

2.3 Risk Assessment of the Choke Points

To answer the second sub-question "What are the key risks and uncertainties associated with rerouting maritime traffic through primary choke points, and how these risks have affected shipping operations and trade flows?", an analysis of the risks which choke points have faced in the past years will be provided. Ang (2021) points out two main risks which influence choke points: structural risks (due to the geophysical structure of the choke points) and geopolitical risks (due to the proximity of the choke points to high politically unstable countries).

2.3.1 Structural Risks

One of the most recent and financially relevant cases regards the blockage of the Suez Canal, in March 2021, by the container ship "Ever Given". The 400-meter-long vessel got stuck due to the high winds and narrowness of the canal. It took over six days and the deployment of many tugboats to free the ship. Following this episode, the Egyptian authorities announced a widening of the narrower parts of the canal. Approximately 30% of global container traffic was delayed and estimations show how the blockage cost the global economy between 2 and 2.5 billion euros bringing direct losses for the owners of Ever Given, for at least a billion euros. Furthermore, many companies chose to divert their voyages through the Cape of Good Hope, following the uncertainty of passage in the canal (Vasic, 2022). The incident demonstrated how disruption in a choke point affects many networks, leading to tangible economic damage to businesses and supply chains. This recent event increased the attention on vulnerabilities in choke points which may arise in the future.

2.3.2 Geopolitical Risks

Since by definition choke points are areas of forced passage without easy alternative routes, vessels are sometimes forced to navigate in territories of highly politically unstable countries. Crossing the Turkish Straits, the Strait of Bab el-Mandeb, the Strait of Hormuz, the Strait of Malacca, and the Suez Canal presents a medium to high risk of facing conflicts, terrorist attacks and piracy (Ang, 2021). The Strait of Hormuz, fundamental for the trade of oil from Middle East countries, has faced geopolitical tensions over the past decades. Compared to other choke points, this Strait is particularly important, as it is the only sea passage from the Persian Gulf, meaning that, in case of closure, oil needs to be transported with inland pipelines. The Iranian Government has threatened multiple times to close the canal, following tensions with Iraq and the US, which led to attacks on ships and seizures (Nadimi, 2023). Maritime piracy and armed robberies were at an all-time low in 2022, with only 115 recordings. The International Maritime Bureau recorded 120 attacks in 2023, which is still a low figure considering the average of 287 attacks per year between 2010 and 2020 (Statista Research Department, 2023). However, it raised concerns over the increasing number of crew taken hostage (41 recordings in 2022 against 73 in 2023) and kidnapped (2 recordings in 2022 against 14 in 2023) (Buitendijk, 2024). The risk of piracy attacks increases not only the operational risk for shipping companies but also raises insurance premia, which can lead to rerouting over some choke points.

3. Methodology and Data

3.1 Transport Costs Models

This section aims to provide an answer for the third sub-question "How do changes in transport costs due to rerouting through the Cape of Good Hope, the Strait of Magellan, and the Drake Passage impact overall maritime shipping costs for different types of vessels?".

3.1.1 General Information on Transport Cost Models

To understand to what extent trade flows will be impacted based on alternative routes from the Panama and Suez Canal, studying the distance between ports of origin and destination is not enough. For a more accurate analysis, there is a need to understand how transport costs change when crossing the secondary choke point of the Strait of Magellan, Drake Passage, and Cape of Good Hope.

Fuel costs mostly depend on the time spent in the sea by the vessel and can vary also based on the size of the ship. Notteboom and Carriou (2009) estimated a fuel consumption model, depending on the size of the vessel and TEU capacity, and found out that larger vessels, as expected, consume more fuel. However, the difference in fuel consumption is not directly proportional to the increase in vessel size, mainly because the amount of cargo that can be carried does not proportionally increase with vessel size. Hence, bigger vessels are more cost-efficient than smaller ones.

Regarding canal fees, Notteboom and Rodrigue (2011) calculated a model to predict the tolls for the Suez Canal based on the weight of the vessel, however, this model does not specify the type of vessel crossing the canal. Despite this, it can still calculate the tolls with an error of 5% depending on the dimensions of the vessel. The results show that bigger ships are more cost-efficient, as vessels of 1,000 TEU pay up to 46$ dollars more per TEU, compared to 13,000 TEU vessels.

Authors often struggle to discuss ships' operational costs due to the secrecy maintained by ship-owners, hence, databases and technical literature can only try to estimate these costs. Furthermore, many variables need to be taken into account when estimating these costs, such as crew wages based on the nationality of the employees, fuel prices in different ports and fluctuating ship prices. It is then probably impossible to correctly estimate the operational costs, especially for larger and more complex vessels. Pocuca (2006) developed one of the most accurate models to estimate costs during a voyage with fixed costs (annual operating costs, depreciation, and maintenance), and voyage costs (daily operating expenses, depreciation, and fuel costs at a given speed). An important statistical tool that helps to analyze shipping operating costs and revenue is the Moore Maritime Index, which extracts data from the financial statements of ship-owning companies and gives more precise insights regarding the operational costs of the 1500 vessels it analyzes (Moore, 2024).

Taking this into account, the following hypothesis is formulated:

1. *Rerouting through the alternative choke points of Cape of Good Hope, the Strait of Magellan and the Drake Passage will lead to higher transportation costs.*

The main take from these models is that longer distances do not always lead to proportionally higher transportation costs. Hence, it is fundamental to study the bilateral trade flow of two countries, not just based on their distances, which are fixed, but on the transportation costs, which can vary depending on the size of the vessel, the operational costs, and the canal fees.

3.1.2 Types of Vessels

Due to the vastity of goods passing through the Panama and Suez Canal, many different types of vessels cross the choke points every day, each of them enabling the trade of different commodities. The Suez Canal Authority (2020) states over 80% of the vessels crossing the canal fall under the definition of tankers, container ships, and bulk carriers, hence, these vessels are the most representative of this study. Hence, it is fundamental to understand their main characteristics.

Liquid cargo ships, also known as tankers, carry a range of liquid cargo. As the name suggests, they are subdivided into different tanks where the cargo is pumped via pipelines. Tankers feature particular safety measures and equipment to reduce the risk of fire and explosions due to the large amount of chemicals. Tankers are subdivided into crude carriers, which load crude oil, product tankers, which transport refined products such as fuels or petroleum, and chemical carriers, designed to transport chemicals in bulk (OneOcean, 2021).

Container ships represent nowadays the most important way of transporting manufactured goods around the world, as containers can be transferred to trucks, trains, and ships relatively easily, enabling multimodal transport and reducing bottlenecks in logistics. Containers can accommodate anything, from food to electrical equipment and cars. Standard containers are usually measured in TEUs (Twenty-foot Equivalent Units) and are generally 20 feet (1 TEU) or 40 feet (2 TEUs). Some containers can also be equipped with engines, in order to ship refrigerated cargo. This kind of vessel is usually made up of several holds equipped with “cell guides” which allow containers to slot into place (OneOcean, 2021).

Bulk carriers carry dry cargoes with a high weight-to-cost ratio, such as coal, grain, copper and ores and enable exploitation economies of scale. They are usually divided into separate holds covered by hatches, and the cargo can be loaded also without the need for shore equipment when cranes are located between each hatch (OneOcean, 2021).

3.1.3 Maritime Trade Routes

Table A1, Table A2, and Table A3 in Appendix A show the different countries this study focuses on, to estimate transport costs. An example is the route going from the Port of Shanghai (China) to the Port of Rotterdam (Netherlands). This route is characterized by high traffic of goods between the two countries, and the fact that vessels can go either from the Suez route or choose the alternative Cape of Good Hope route. Furthermore, many Chinese companies have businesses in the Port of Rotterdam, leading to an interdependency between the two countries (Putten et al., 2023). A different route goes from the Port of San Antonio (Chile) and the Port of Rotterdam as it is possible to operate it through the Panama Canal, the Strait of Magellan, or the Drake Passage. Regarding the Suez routes, the gravity model will take into account all European countries with at least one port and the ten Asian countries with the busiest ports. Regarding the Panama route, the gravity model will take into account Chile, Ecuador, Peru and USA and all European countries with at least one port. The countries in the American continent have been chosen as, due to their geographical positions, they are forced to operate either through the Strait of Magellan, the Drake Passage, or the Panama Canal. The only exception regards the USA as ports on the east side of the country can easily reach European countries without crossing the relevant choke points mentioned in this study. However, the USA is the largest user of the Panama Canal, due to the importance of some ports on the west side of the country, such as the one in Los Angeles (Roy, 2023): hence, it is significant to study bilateral trade flow also for this country. In the next chapters the routes will be labelled with the name of the main choke point the vessels cross during the voyage: for example, the Magellan Route will go through the Strait of Magellan, the Cape Route will go through the Cape of Good Hope, and so on.

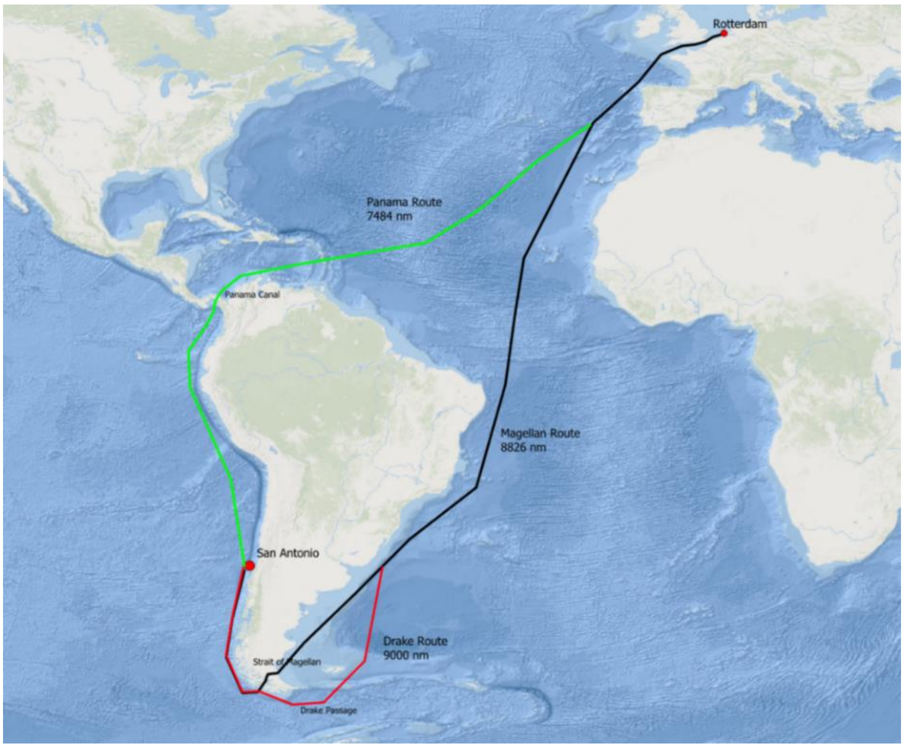

Figure 4. The San Antonio-Rotterdam Voyage on the Panama, Magellan and Drake Routes. Source: own composition

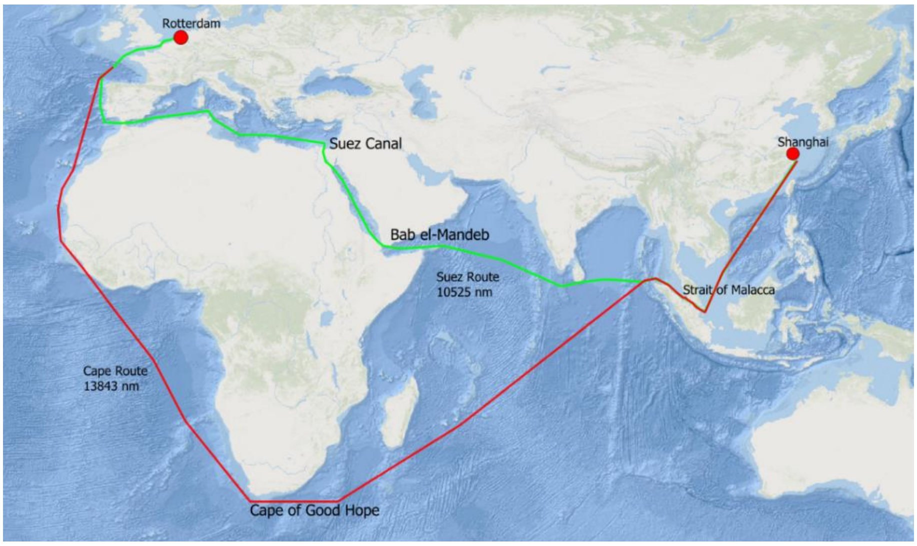

Figure 5. The Shanghai-Rotterdam Voyage on the Cape and Suez Routes. Source: own composition

3.1.4 Assessment of the Daily Transport Costs of the Vessels

As already mentioned, fuel consumption is not directly proportional to the size of the vessel. Based on the distance travelled in nautical miles, it is possible to estimate the fuel consumption of the voyage. The reference fuel for the study will be Very Low Sulphur Fuel Oil (VLSFO), which has been the main answer to the need for vessels to meet the IMO 2020 requirements on Sulphur emissions and accounts now for the biggest share of marine fuel used (Einemo, 2021). Hence, the following formula will be developed to estimate fuel costs:

$$Voyage\ Fuel\ Consumption = fuel\ consumption\ on\ laden\ voyages\ \left[\frac{\text{kg}}{\text{nautical miles}}\right] \times$$
$$distance\ in\ nautical\ miles\ (nm) \times global\ average\ bunker\ VLSFO\ prices\ \left[\frac{€}{\text{kg}}\right]\ (1)$$

Tables B1 and B2 in Appendix B answer the previous formula.

Operational costs will be calculated with the following formula:

$$Operational\ Costs = average\ vessel\ speed \frac{\left[\frac{\text{nautical miles}}{day}\right]}{nautical} miles\ of\ the\ route\ (nm)\ \times$$
$$daily\ operational\ costs\ (\$)\ (2)$$

Tables B3 and B4 in Appendix B, show the total operational costs for the vessels.

Difference categories of vessels will be studied to make transport costs as accurate as possible. The categories are based on the different sizes of the vessels and can be found in Tables B5, B6 and, B7 in Appendix B.

Canal tolls and pilotage fees will be calculated as the average transit fee for different sizes of vessels. Results can be found in Tables B8, B9, B10 and B11 in Appendix A.

Hence, to answer sub-question 2, transport costs will be calculated as the sum of fuel burned in the route, operational costs and canal tolls and pilotage fees (if present):

$$Transport\ Costs = Voyage\ Fuel\ Consumption\ Costs\ (\$) +\ Operational\ Costs(\$) +$$
$$Canal\ Tolls(\$) +\ Pilotage\ Fees(\$)\ (3)$$

The following variables will then be analyzed:

Table 1. Variables in Transport Costs Models

Relevant Variable	Definition
Distance	Distance between the two ports in nautical miles (nm)
Fuel Consumption	Consumption on laden voyages in kg/nm
Average VLSFO Price	Average VLSFO bunker price on the 29th of May in 2024
Average Vessel Speed	Average vessel speed in nm/hour
Daily Operational Costs	Average daily operational costs in USD such as crew salaries, insurances, administration, etc.
Canal Tolls	Expected canal tolls for crossing the Panama and Suez Canal
Pilotage Fees	Expected pilotage fees for crossing the Strait of Magellan

3.2 The Gravity Model

3.2.1 General Information on the Gravity Model

Jan Tinbergen (1963) borrowed the gravity equation from physics in 1962, in order to explain bilateral trade flow. Similarly to planets, mutually attracted based on their proportion and sizes, countries trade in proportion to their GDPs and proximity. The original form of the gravity model was proposed as follows:

$$T_{ij} = \frac{\alpha G_i G_j}{Dij} \quad (9)$$

here, T_{ij} represents the bilateral trade volume between country i and country j, G_i and G_j are the GDPs of country i and country j, and D_{ij} is the spatial distance between country i and country j; α is constant.

At that time, other models of international trade, such as the Ricardian model or the Hecksher-Ohlin model, could not provide the foundation for the gravity model (UNCTAD, 2024). The stability and effectiveness of the gravity equation in explaining bilateral trade flows have led to new theoretical studies. Anderson (1979) proposed a model where goods were differentiated by country of origin and consumers had preferences over all differentiated products, leading to extensive trade, with larger countries importing and exporting more. Transit costs were labelled as "iceberg costs", assuming that a fraction of the goods shipped "melt" in transit (Irrazabal et al., 2010). However, per-unit transport costs consist not only of ad-valorem costs (such as iceberg costs) but also of insurance premia, tariffs, and other components that are not necessarily proportional to the good's producer price (Bosker et al., 2018). Later on, the theoretical progress of the model was manifested in modelling, based on both the demand and supply sides. Wei (1996) studied the demand side and described how intranational and international trade are related, by establishing a gravity model based on constant-elasticity-of-substitution (CES) monopolist competition. Regarding the supply side, Eaton and Kortum (2002) studied structural equations for bilateral trade using the concept of Ricardian competitive advantage. About the empirical progress, numerous studies have been conducted following the development of econometrics. These models can be subdivided into four dimensions (Li et al., 2020):

a) Diverse variables

The most important analysis elements for the gravity model used by researchers are gross domestic product (GDP) or gross national product (GNP), population, and distance. However, the empirical progress on the gravity model showed the addition of many dummy variables to make the models more precise: these include language, social system, colonial status, reciprocal trade agreements, cultural similarities, political instability etc. Dummy variables can help to measure trade costs, however, they are not the only indicators used: studies also used time-varying variables, such as exchange rates in the gravity equation. Due to limited data availability, transportation costs were not fully able to replace straight-line distance. Hence, more recent studies have tried to make changes to quantify more precisely the real costs: Huang (2007) estimated transport costs among trade routes originating from countries with high uncertainty aversion.

b) Diverse regression models

In the past years, an increasing number of regression methods have been proposed to study the gravity model. Studies in the 21st century have adjusted and optimized the estimation methods to predict trade flows more accurately (Li et al., 2020). As the original form of the model is mathematically nonlinear, in economic geography it is common to take the logarithm of both sides of the gravity equation, to estimate the regression under linear conditions. Moreover, researchers have been using panel data to investigate time series and cross-sections. To fit data, two main techniques have been employed, fixed-effects (FE) and random-effects (RE). The FE estimator assumes that the model has an unobserved heterogeneous component that is constant over time and affects both trading parties (countries, continents etc.) in different ways. The RE estimator is a generalization of the classical linear model, which means that the regression coefficient of the FE model is studied as a random variable. One of the risks of using this model is that, in the presence of heteroscedasticity, the linear regression will lead to inefficient estimations: hence, studies have started to use different techniques from linear regression methods, such as nonlinear least squares (NLS) and gamma and Poisson pseudo maximum likelihood (GPML and PPML).

c) Single commodity trade

Research on the gravity model has not only been based on total trade volumes, but also on the trade transactions of single commodities (Li et al., 2020). For example, concerning perishable goods, whose quality can be affected by the time of transport, the gravity model is fundamental to understand how longer distances can lead to higher costs of transport.

d) Different study scales

Most research focuses on three scales to analyze trade:

-Global

-Continental (as continents have different development situations, it is significant to distinguish between them when studying the gravity model).

-National (studying a single country leads to understanding the potential advantages or disadvantages of exporting a product by establishing the trade flow with other countries).

Taken all this into account, a more mature gravity equation has been proposed, forming a general linear expression, which is convenient for empirical testing. The standard procedure for estimating a gravity equation is to take natural logarithms of all variables and obtain a log-log equation which can be estimated by ordinary least squares regression. Here is an example:

$$\ln T_{ij} = \alpha_0 + \alpha_1 \ln G_i + \alpha_2 \ln G_j + \alpha_3 \ln P_i + \alpha_4 \ln P_j + \alpha_5 \ln D_{ij} + \alpha_6 X_1 + \ldots + \alpha_k X_p + \mu \quad (5)$$

where P_i and P_j are the populations, G_i and G_j are the GDPs, and D_{ij} is the distance, of countries i and j, while$X_1,\ldots X_p$ represent other variables, including dummy variables such as language and religion, and μ is a random error term (UNCTAD, 2024).

3.1.2 The Augmented Gravity Model with Transport Costs

The gravity model of trade suggests that trade between two countries is proportional to their economic sizes (GDPs) and inversely proportional to the distance between them, accounting only for bilateral trade costs, such as tariffs or cultural ties. The original model fails to take into account the fact that countries' trade is also influenced by their trading costs with all other partners. Anderson and Wincoop (2003) estimated a gravity model introducing multilateral resistance terms to address this limitation, with two types of multilateral resistance terms. Inward multilateral resistance represents how difficult it is for a country to import from the world, considering all bilateral trade costs. Outward multilateral resistance measures how difficult it is for a country to export to the world. Hence, the Anderson and Wincoop (2003) proposed the following model:

$$Trade_{ijt} = \frac{y_{it} y_{jt}}{y_{wt}} \left(\frac{\tau_{ijt}}{P_i P_j}\right)^{1-\sigma} \quad (6)$$

In logs:

$$\ln(x_{ij}) = \ln(y_i) + \ln(y_j) - \ln(y_2) + (1 - \sigma)(\ln(\tau_{ijt}) + \ln(P_i) + \ln(P_j)) \quad (7)$$

$Trade_{ijt}$ refers to the bilateral trade between country i and country j, y_{jt} and y_{wt} are respectively the incomes of countries i, j, and the world. τ_{ij} is a bilateral resistance term, which comprises all pair specific barriers such as common language, distance, colonial ties, etc., and P_i and P_j are country specific multilateral resistance terms.

Feyrer (2021) simplifies the equation and estimates it as:

$$\ln(trade_{ijt}) = \alpha + \gamma_{ij} + \gamma_t + \beta \ln(seadistance_{ij}) + \epsilon \quad (8)$$

In this equation, the pair of dummies, made possible through the time variation in distance, controls for all long-run determinants of bilateral trade such as colonial heritage, shared tastes, etc. In Feyrer's model, the individual income terms are time varying and cannot be perfectly controlled by the pair dummies. However, the author assumes that, since the shock is exogenous to any particular country's income, this will not bias the result.

Based on the enhanced gravity equation and the model from Freyer (2021), the following equation will be developed to study the change in trade flows caused by the increased transport costs and sea distances following the rerouting of the voyages through the Strait of Magellan, the Drake Passage or the Cape of Good Hope:

$$\ln(Bilateraltrade_{ij}) = \alpha + \beta_1(lnGDP_i) + \beta_2(lnGDP_j) + \beta_3 lnPopulation_i + \beta_4 lnPopulation_j + \beta_5 ln\Delta Seadistance_{ij} + \beta_6 ln\Delta Transportcosts_{ij} + \epsilon_{ij} \quad (9)$$

where:

i	denotes the origin country and depending on the model refers to either Asian or American countries
j	denotes the destination country and always refers to European countries
$Bilateraltrade_{ij}$	is the dependent variable and represents the amount of bilateral trade (exports and imports between country i and country j
GDP_i & GDP_j	represent the gross domestic products of countries i and j in $
$Population_i$ and $Population_j$	represent the population in countries i and j
$\Delta Seadistance_{ij}$	shows the change in distance which results from rerouting the voyage through the alternative choke point
$\Delta Transportcosts_{ij}$	shows the change in transportation costs which results from rerouting the voyage through the alternative choke point, calculated with equation 3
ϵ_{ij}	is the error term, which captures the unobserved factors affecting bilateral trade flows between countries i and j

When estimating the gravity model of trade there is the risk to incur in a significant proportion of zero observation, as many countries do not trade with each other. To mitigate these effects, a PPML estimator will be employed, as it helps to deal with zero-trade flow count data by modelling the probability of observing zeros and incorporating them into the estimation process. This is helpful as a normal log transformation of the trade flow would lead to a substantial and non-random neglect of the observations (Gerritse, 2021).

Hence, a second hypothesis will be formulated:

2. *The increased transportation costs and sea distances, which results from rerouting through the secondary choke points of the Strait of Magellan, Drake Passage and Cape of Good Hope, are associated with a decrease in bilateral trade flow.*

Model 1 will represent the gravity model applied to the Panama and Magellan routes, Model 2 will represent the gravity model applied to the Panama and Drake routes, and Model 3 will represent the gravity model applied to the Suez and Cape route. Each model has been run separately for all countries and routes in STATA. Specifically, 10 countries will be studied in the Asian area, 27 in the European area, and 4 in the American one for a total of 31 countries in Models 1 and 2 and 37 in Model 3. Descriptive statistics for the three models can be found in Tables C1, C2 and C3 of Appendix C.

3.3 Data

3.3.1 Vessel's transport costs

To analyze the transport costs of the vessels, different databases and sources will be used. The European Maritime Safety Agency collects data to ensure that all ship owners comply with the regulations of the European Commission and the International Maritime Organization. The fuel consumption data will be retrieved from the latest report released for the year 2022, where it is possible to find the average fuel consumption on laden voyages, where laden stands for vessels loaded with full cargo (EMSA, 2024). The distance in nautical miles of the different voyages will be retrieved from the website sea-distances.org and the average speed of the vessels will be retrieved from the Statista dataset "Average speed of vessels in the world merchant fleet in 2018, by ship type" (Placek, 2023). The global 20 ports average price for VLSFO will be retrieved from shipandbunker.com.

Data on daily operational costs will be retrieved from the Moore Maritime Index (Moore, 2024), which collects and sorts the average costs in 2022 for bulk carriers, tankers and container ships.

The official websites of the Panama and Suez Canal offer a breakdown of the expected tolls based on the type of vessel taken into consideration. Specifically, the Panama Canal asks for the vessel type, the lock which will be used, the TEU capacity/DWT/Vehicle Capacity/m3, the ship status, length, and beam. Besides this data, the Suez Canal also requires information regarding the Suez Canal Net Ton and Gross Ton, a unit of measurement representing the revenue-earning capacity of the vessel.

Furthermore, the official website of the Chilean Authorities offers a tool to calculate the expected fee to pay for the pilotage through the Canal.

The change in transportation costs will be calculated, as the difference between the original route and alternative route costs estimated with formula 3.

3.3.2 Trade Flows and Macroeconomic Variables

Data on the bilateral trade flows between countries will be retrieved from the UN Comtrade (2024) database. Since trade flows in 2023 are not yet fully uploaded, data from 2022 will be retrieved. Data on GDP and Population in 2022 will be retrieved from the databases of the World Bank (2024a, 2024b).

4. Results

4.1 Voyage Costs

This section aims to discuss hypothesis 1: rerouting through the alternative choke points of the Cape of Good Hope, the Strait of Magellan and the Drake Passage will lead to higher transportation costs. To understand how transport costs vary through the different routes, equation 3 has been performed.

Table 2. Total Transport Costs on the Shanghai-Rotterdam Route

Vessel	**Suez Route**	**Cape Route**
Crude Oil Tanker	$ 2,907,784	$ 3,132,622
Dry Bulk Carrier	$ 1,869,037	$ 2,020,487
Container Ship	$ 2,396,488	$ 2,836,221

Note. Example of Total Transport Costs calculated with formula (3) for the Shanghai-Rotterdam route.
Source: author's calculation.

Table 3. Total Transport Costs on the San Antonio-Rotterdam Route

Vessel	**Panama Route**	**Magellan Route**	**Drake Route**
Crude Oil Tanker	$ 1,908,931	$ 2,048,234	$ 2,036,669
Dry Bulk Carrier	$ 1,246,707	$ 1,321,017	$ 1,313,595
Container Ship	$ 1,690,709	$ 1,845,489	$ 1,843,963

Note. Example of Total Transport Costs calculated with formula (3) for the San Antonio-Rotterdam route.
Source: author's calculation.

Tables 2 and 3 show an example of the total transport costs through the different routes. As expected, despite the high canal tolls, the Suez and Panama routes are less costly for shipping operators. However, these costs vary from country to country. Table 4 shows the average difference in costs resulting from rerouting through the secondary choke points for all the countries.

Table 4. Average Difference in Transport Costs Through Alternative Routes

Cape Route	Magellan Route	Drake Route
$ 358,712	$ 560,231	$ 525,812

N*ote. Source: author's calculation.*

After conducting the analysis, it has been found that rerouting through the alternative choke points leads to higher transportation costs. It may still be profitable to operate through alternative routes when the higher costs are transferred to final customers, such as increasing shipping fees for containers, however, this may result in lower trade flows. Therefore, hypothesis 1, which stated that the alternative routes would result in higher transportation costs, is supported by the findings of this study.

4.2 Effects of Higher Transportation Costs in Trade Flows

This section aims to explain the effects of the increased transport costs and distances on trade flows between economic partners of different regions of the globe and answer sub-question 4: what are the specific effects of increased transport distances and costs on bilateral trade flows between major trading partners in different areas of the worlds, specifically focusing on the routes affected by the Panama and Suez Canal closures?

Table 3. PPML estimation for augmented gravity equation (9)

Variable	Model 1	Model 2	Model 3
$lnGDP_i$	0.036	0.042*	0.016***
	(0.023)	(0.0201)	(0.002)
$lnGDP_j$	0.033***	0.032**	0.071***
	(0.007)	(0.007)	(0.016)
$lnPopulation_i$	-0.033	-0.040	0.013***
	(0.0435)	(0.039)	(0.008)
$lnPopulation_j$	0.034***	0.034*	-0.021**
	(0.0435)	(0.0057)	(0.008)
$ln\Delta Seadistance_{ij}$	-0.011**	0.061	-0.087**
	(0.0341)	(0.0610)	(0.039)
$ln\Delta Transportcosts_{ij}$	-0.022	0.009	-0.053*
	(0.017)	(0.029)	(0.028)
Constant	0.658***	0.746**	0.152***
	(0.113)	(0.103)	(0.152)

Observations	108	108	270

*Note. Standard errors are in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01. Model 1 represents the gravity model applied to the Panama and Magellan routes, Model 2 represents the gravity model applied to the Panama and Drake routes, and Model 3 represents the gravity model applied to the Suez and Cape route.*

The results from model 1 show that the coefficient of GDP from the European countries is positive and statistically significant at the 1% level, suggesting that a 1% increase in the GDP from a European country is associated with a 0.33% increase in bilateral trade flow. The coefficient from the population of the European countries is positive and statistically significant at the 1% level, suggesting that a 1% increase in population from a European country is associated with an increase in bilateral trade flow by 3.4%. Moreover, the coefficient of the difference in sea distances is negative and significant at a 5% level, meaning that a 1% increase in trade flow will lead to a reduction in bilateral trade flow by 2.2%. The other coefficients do not show any significant impact on bilateral trade flow on this route.

The results from model 2 show that both coefficients of GDP are positive, with the American GDPs being statistically significant at a 10% level, and the European GDPs at a 5% level: respectively, a 1% increase in American GDP is associated with a 4.2% increase in bilateral trade flow, while an increase in 1% in European GDP is associated with an increase in bilateral trade flow by 3.2%. The positive and significant at the 10% level coefficient of the population from European countries shows that a 1% increase in this variable is associated with an increase in bilateral trade flow by 3.4%.

All coefficients in model 3 are significant at different levels. The coefficients for American and European GDPs are statistically significant at the 1% level: the first one shows that an increase in 1% in American and European GDP is associated respectively to an increase in bilateral trade flow by 1.6% and 7.1%. The coefficient of Asian population is statistically significant at the 1% level, meaning that a 1% increase in Asian population is associated with a 1.3% increase in bilateral trade flow. Regarding the coefficient of the European population, this is statistically significant at a 5% level and a 1% increase in the European population is associated with a reduction in bilateral trade flow by 2.1%. The coefficient representing the difference in distance between the Asian and European countries is negative and significant at a 5% level, showing that an increase in 1% in distance is associated with a reduction in bilateral trade flow by 8.7%. Moreover, the coefficient representing the difference in transportation costs which results from the alternative routes is negative and statistically significant at a 10% level, showing that a 1% increase in transportation costs lead to a 5.3% reduction in bilateral trade flow.

4.3 The Effects of Alternative Trade Routes in Shipping

This section aims to answer the fourth sub-question "What are the specific effects of increased transport distances and costs on bilateral trade flows between major trading partners in different areas of the world, specifically focusing on the alternative routes affected by the Panama and Suez Canal closures?", by analyzing and interpreting the coefficients in the gravity models.

4.3.1 The Effects of GDPs

The significant and positive coefficients of GDPs in the models are in line with authors that have worked on gravity models of trade in the past years. Firstly, Tinbergen suggested and studied that countries with higher GDPs would be more likely to trade with each other; subsequent analyses from different authors confirmed the intuition of Tinbergen, which augmented gravity models and different regression techniques (Tinbergen, 1963; Anderson & Wincoop, 2003, Li et al., 2020).

4.3.2 The Effects of Populations

Khayat (2019) found that countries with higher populations would also be more likely to trade with each other. However, Model 3 in this study unexpectedly shows that an increase in the percentage of the population in European countries would lead to an increase in the percentage of bilateral trade flows, while the opposite applies to the Asian population. These results, also presented by Li et al. (2020), could be justified by multiple reasons. For example, some European countries may have larger populations but lower consumption levels per capita compared to some Asian countries; as a result, an increase in population in Europe may not lead to a proportional increase in trade flows. However, many countries studied for the Asian route estimations, such as the Philippines, Vietnam or India, present lower consumption levels per capita and larger populations, compared to some European countries, such as Germany, France, or Italy (World Bank, 2024c), hence, this reasoning does not justify the sign of the coefficient. It is more likely that the size of the coefficient is to be attributed to the trade composition between the two continents: indeed, the types of goods traded between European and Asian countries differ significantly. Hence, a higher demand or higher value-added of products by Asian countries, compared to the European ones, could justify the size of the coefficient.

4.3.3 The Effects of Sea Distances

Another common finding between authors shows that trade is negatively related to distances (Tinbergen, 1963; Anderson & Wincoop, 2003, Li et al., 2020). The gravity equation of this study has been specifically augmented, with the differences in sea distances between the ports on the routes through the Panama and Suez Canal, and their related secondary choke points; this has been done to make estimations more accurate compared to models where the geographical differences between countries has been retrieved from general databases. The results from the negative coefficients of difference in sea distance between the ports, in Models 2 and 3, show that higher percentages in distances are associated with lower bilateral trade flows, in line with other studies.

4.3.4 Final Results

This research aimed to study the relationship between transport costs and bilateral trade flow. Despite the higher transportation costs on the alternative routes, the results from Models 1 and 2 did not support hypothesis 2, as they did not show any significant effect on the difference in transportation costs on bilateral trade flow. Therefore, hypothesis 2 can be rejected for Models 1 and 2. On the other hand, model 3 showed that a higher percentage of transportation costs is associated with a lower bilateral trade flow. One of the reasons that may have influenced the significance of Models 1 and 2 has been the lack of available data compared to Model 3, as studying the routes going through the Panama Canal can be complicated, as only a few countries can benefit from the alternative routes of the Strait of Magellan and the Drake Passage.

Furthermore, despite this research focused on all the countries that are mostly affected by the droughts in Panama, there may be unobserved effects due to the fact that many ships do not just cross the Panama Canal, but also stop there. Goods are then unloaded in Panama and transported by rail, road, or smaller vessels to South American countries, enabling multimodal transportation. However, rerouting may result in a dispersion of trade, as larger vessels going through the secondary choke points will stop in South American countries, and the effects on the intermodal transportation costs may be difficult to capture. Model 3 presents more accurate data due to the high traffic of trade through the selected countries. The high demand for Asian goods from European countries leads to a higher and more precise set of data. Furthermore, it has been possible to analyze a bigger set of countries compared to Model 1 and 2, which were limited by the geographical conditions of that area. In contrast to Models 1 and 2, Model 3 provided evidence in line with hypothesis 2, indicating that higher transportation costs and sea distance are associated with a lower bilateral trade flow. Hence, while the models regarding the Panama, Drake and Magellan routes do not provide evidence for hypothesis 2, the results from Model 3, in regard to the Suez and Cape routes align with hypothesis 2. Then, hypothesis two cannot be rejected based on the results from Model 3.

5. Discussion

This section will discuss the four sub-questions individually before addressing the main research question.

Sub-question 1: What are the historical developments and current operational characteristics of the Panama and Suez Canal?

The Panama and Suez Canal have gone through significant historical developments and operational changes since their construction. The Panama Canal, completed in 1914 with the help of the USA, represents one of the most ambitious engineering projects, providing a maritime link between the Atlantic and Pacific Oceans. The latest expansion in 2016 improved the canal's capacity and added a new lane of traffic with two new sets of locks. Similarly, the Suez Canal opened in 1869, represents a crucial maritime link between Europe and Asia. The latest expansion, completed in 2015, increased the canal's capacity and reduced waiting times for ships.

Sub-question 2: What are the key risks and uncertainties associated with rerouting maritime traffic through primary choke points, and how have these risks affected shipping operations and trade flows?

The key risks and uncertainties include structural risks, such as narrow passages and reliance on natural resources, and geopolitical risks involving political instability and related potential blockades or delays. Both risks have a tangible impact on shipping operations and trade flows. The Red Sea crisis, caused by the Iranian Houthi movement targeting vessels in the Bab el-Mandeb Strait and Suez Canal, has raised the attention of the media on geopolitical risks in maritime shipping. On the other side of the world, the Panama Canal is suffering from a lack of water in Gatun Lake, which is the main resource to enable the functioning of the lock systems in the choke point.

Sub-question 3: How do changes in transport costs due to rerouting through the Cape of Good Hope, the Strait of Magellan, and the Drake Passage impact overall maritime shipping costs for different types of vessels?

Changes in transport costs due to rerouting significantly impact maritime shipping costs with increasing fuel costs, operational expenses, and transit times. This study focused on understanding the change in costs for three different types of vessels: dry bulk carriers, crude oil tankers, and container ships. Empirical results indicate that, for all vessels, the increase in transport costs is substantial, despite the high canals transit fees.

Sub-question 4: What are the specific effects of increased transport distances and costs on bilateral trade flows between major trading partners in different areas of the world specifically focusing on the routes affected by the Panama and Suez Canal closures?

The models presented different results with regard to the increase in transportation costs and sea distances. While an increase in sea distance is associated with a lower of bilateral trade flow on the Magellan Route, there is no evidence for the same finding on the Drake Route. Furthermore, there is no evidence in Models 1 and 2 that higher transportation costs are associated with lower bilateral trade flows. On the other hand, Model 3, concerning the Cape of Good Hope route, showed that higher sea distances and transportation costs lead to a lower bilateral trade flow.

This study aimed to provide an answer to the research question:

How do geopolitical instability and natural disasters in the primary choke points of Panama and Suez Canal influence bilateral shipping trade?

The rerouting of trade vessels through the alternative and secondary choke points of the Cape of Good Hope, the Strait of Magellan, and the Drake Passage in response to the disruptions in the Panama and Suez Canal significantly impacts global trade flow by increasing transportation costs and sea distances. The empirical analysis of this study used an augmented gravity model to answer the research question: as evidenced, rerouting through the Cape of Good Hope, the Strait of Magellan, and the Drake Passage results in an average cost increase of $357,712 (+16.7% compared to Suez Route), $560,231 (+26.1% compared to Panama Route), and $525,812 (+25.5% compared to Panama Route) respectively. The findings in the gravity models suggest that, while rerouting through the secondary choke points is a feasible alternative during disruptions, it has a significant economic impact which can lead to lower bilateral trade flow.

5.1 Conclusion

This paper provided a comprehensive analysis of the impact of geopolitical instability and natural disasters on maritime transport routes and choke points, with a focus on the Panama and Suez Canal, for the disruptions they are currently facing. The research aimed to determine how these disruptions influence transportation costs and bilateral trade flows and tried to understand the feasibility of rerouting voyages through the secondary choke points of the Cape of Good Hope, the Strait of Magellan and the Drake Passage.

Despite the different operational costs and fuel consumption of the vessels studied, the empirical analysis confirmed that rerouting leads to significantly higher transportation costs for shipping operators compared to the routes through the primary choke points of the Panama and Suez Canal.

The augmented gravity equation revealed different results for each model. Model 3, being also the most significant, presented findings similar to the ones of other authors who have researched in this field, such as Tinbergen (1963) and Anderson & Wincoop (2003). It showed that a 1% increase in transportation costs, resulting from rerouting through the Cape of Good Hope, is associated with a 5.3% reduction in bilateral trade flow, while a 1% increase in sea distance leads to an 8.7% decrease in trade flow.

This research highlighted the effects associated with relying on primary maritime choke points in conditions of geopolitical instability and natural calamities. The recent droughts in Panama and the Red Sea crisis represent only two of the many disruptions which primary choke points have been facing. Indeed, as Ang (2021) points out, there are many other primary choke points threatened by high structural and geopolitical risks. As each choke point is associated with specific characteristics and different compositions in trade patterns, it is fundamental that research is done to inform maritime stakeholders of the possible consequences of future disruptions in these waterways.

In conclusion, although this study aims to help understand how disruptions in the primary maritime choke points of Panama and Suez influence transportation costs and bilateral trace flow, the maritime field is so extended that further research is needed for strategic planning and investments to mitigate the risks associated with these essential trade routes.

5.2 Limitations

While this study aimed to provide insights into the relationship between maritime routes through different choke points, transport costs, and bilateral trade flows, several limitations should be acknowledged. Firstly, the use of data from 2022 for trade flows may not fully capture the dynamics of trade patterns in subsequent years. The invasion of Ukraine from Russia in February 2022 resulted in a negative shock for some economies with the price of energy and gasoline being extremely volatile during that year. Furthermore, the estimation of transport costs and distances between ports involved simplifications and assumptions that may not fully reflect real-world conditions. As already mentioned, larger vessels do not tend to go directly from on distant port to another but prefer to stop at different ones during the route, to enhance the efficiency of transshipment, intermodal transport, and economies of scale. Some of the transport costs then studied in this paper, such as the operational and fuel related ones, can also be labelled as "iceberg" costs, as they "melt" during the voyage (Irrazabal et al., 2010). Indeed, the higher costs will melt during the voyage as companies will take the advantage of transshipment, stopping through various ports in longer routes. Furthermore, the scope of this study was limited to certain areas of world and specific trade routes, which may overlook the complexities of trade dynamics and may not account for factors influencing trade, such as regulatory changes or technological advancements. Specifically, geographical restrictions such as the ones in Models 1 and 2 may have influenced the gravity estimation and availability of data on the possible routes. Lastly, this paper also aimed to study whether there were significant differences in the gravity estimation when the bilateral trade of different commodities, instead of the total trade, was taken into account. As an example, the trade of ores regarding dry bulk carriers, or crude oil regarding tankers, could have been studied. However, due to a lack of sufficient data on trade, especially regarding Models 1 and 2, the analysis did not provide any sufficient proof that the difference in commodity and vessel could influence bilateral trade flow.

5.3 Further Research

Further research on the impact of alternative routes is necessary to address the needs of different maritime stakeholders when geopolitical instabilities or natural catastrophes disrupt choke points. Firstly, expanding the analysis to include a wider range of countries, regions, and trade routes may provide a more comprehensive understanding of global trade patterns. Augmenting the gravity models and examining trade flows of areas such as the Asia-Pacific region (concerning the Panama routes), and the African or Middle East region (regarding the Suez routes), can enhance the accuracy of trade flow predictions. Furthermore, analyzing the implications of emerging trends in the maritime industry, such adoption of alternative fuels (methanol, ammonia, etc.) may be helpful to researchers and shipping carriers. Most importantly, the author invites any reader or researcher to enhance the models of this paper and use the transportation data to analyze the bilateral trade flow of different commodities. For some countries whose economies are highly reliant on specific commodities, such as Middle Eastern countries with crude oil, this can provide more specific and significant results in understanding how to manage disruption in primary choke points.

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Appendix A

This appendix consists of the different ports chosen for the evaluation of the transport costs.

Table A1. European Countries

Country	**Port**
Albania	Durres
Belgium	Antwerp
Bulgaria	Varna
Croatia	Rijeka
Cyprus	Limassol
Denmark	Copenhagen
Estonia	Tallin
Finland	Helsinki
France	Marseille
Germany	Hamburg
Greece	Piraeus
Iceland	Reykjavik
Ireland	Dublin
Italy	Genoa
Latvia	Riga
Lithuania	Klaipeda
Malta	Valletta
Netherlands	Rotterdam
Norway	Oslo
Poland	Gdansk
Portugal	Lisbon
Romania	Constanța
Slovenia	Koper
Spain	Barcelona
Sweden	Gothenburg
Ukraine	Odessa
United Kingdom	Felixstowe

Note. Source: Retrieved from: https://www.searates.com/maritime/.

Table A2. Asian Countries

Country	**Port**
China	Shanghai
Singapore	Singapore
South Korea	Busan
Honk Kong	Honk Kong
Malaysia	Tanjung Pelepas
Thailand	Laem Chabang
Vietnam	Saigon
Indonesia	Tanjung Priok
India	Mundra
Philippines	Manila

Note. Source: The Top 50 Container Ports. World Shipping Council. Retrieved from: https://www.worldshipping.org/top-50-ports.

Table A3. American Countries

Country	**Port**
USA	Los Angeles
Chile	San Antonio
Ecuador	Guayaquil
Peru	Callao

Note. Source: https://www.searates.com/maritime/.

Appendix B

This appendix consists of the data analysis for the transportation costs of the different vessels. Because of the large amount of data and routes, the two already mentioned San Antonio-Rotterdam and Shanghai-Rotterdam routes will be shown as examples.

Table B1. Average Fuel Consumption

Vessel	Crude Oil Tanker	Bulk Carrier	Container Ship
Average fuel consumption	145.84	97.03	194.47
Observations	414	662	467

Note. Consumption in kg/nautical mile on laden voyages. Source: 2022-v200-15052024-EU MRV Publication of information. (EMSA, 2024).

Table B2. Total Fuel Costs for Each Route

Vessel	Suez Route	Cape Route	Panama Route	Magellan Route	Drake Route
Crude Oil Tanker	$ 953,891	$ 1,254,723	$ 678,346	$ 799,985	$ 815,756
Dry Bulk Carrier	$ 634,701	$ 834,790	$ 451,316	$ 532,244	$ 542,717
Container Ship	$ 1,272,084	$ 1,673,108	$ 904,539	$ 1,066,737	$ 1,087,767

Note. Total Fuel Costs calculated with formula (1) for the routes Shanghai-Rotterdam and San Antonio-Rotterdam. VLSFO price of 621.5 $/mt retrieved from Global 20 Port Average the 28th of May 2024 in USD. Source: (https://shipandbunker.com/prices, 2024).

Table B3. Weighted Average Operational Costs

Vessel	Crude Oil Tanker	Dry Bulk Carrier	Container Ship
Total	$ 30,767	$ 22,818	$ 30,147
Observations	109	577	88

Note. Average daily operational costs in USD in 2022. Source: Moore Maritime Index. (2024).

Table B4. Total Operational Costs for Each Route

Vessel	Suez Route	Cape Route	Panama Route	Magellan Route	Drake Route
Crude Oil Tanker	$ 1,427,790	$ 1,877,899	$ 1,015,257	$ 1,197,308	$ 1,220,913

Dry Bulk Carrier	$ 901,499	$ 1,185,697	$ 641,028	$ 755,975	$ 770,878
Container Ship	$ 884,329	$ 1,163,113	$ 628,819	$ 741,576	$ 756,196

Note. Route Operational Costs calculated with formula (2) for the routes Shanghai-Rotterdam and San Antonio-Rotterdam. Source: author's calculation.

Table B5. Crude Oil Tankers

Ship Size	IMO Number	Example Ship	Gross Tonnage (GRT)	Deadweight Tonnage (DWT)	Length Overall (m)	Beam (m)	Draft (m)
Panamax	9868132	BEI HAI QI LIN	43,551	64,900	225	38	14
Aframax	9783007	NORDPENGUIN	60,100	112,000	237	44	15
VLCC	9732553	AEGEAN	154,100	300,000	332	60	22

Note. Length, Beam and Draft measured in meters. Vessels have been randomly chosen based on their sizes. Source: (https://www.vesselfinder.com/vessels, https://www.marinetraffic.com, 2024).

Table B6. Dry Bulk Carriers

Ship Size	IMO Number	Example Ship	Gross Tonnage (GRT)	Deadweight Tonnage (DWT)	Length Overall (m)	Beam (m)	Draft (m)
Supramax	9284477	ASIA STAR	29,000	52,000	188	32	12
Panamax	9153056	SEAEAGLE	37,700	72,000	225	32	12
Suezmax	9435648	CAPE ASTRA	90,000	170,000	290	45	18

Note. Length, Beam and Draft measured in meters. Vessels have been randomly chosen based on their sizes. Source: (https://www.vesselfinder.com/vessels, https://www.marinetraffic.com, 2024).

Table B7. Container Ships

Ship Size	IMO Number	Example Ship	Gross Tonnage (GRT)	Deadweight Tonnage (DWT)	TEU	Length Overall (m)	Beam (m)	Draft (m)
Feeder	9148520	MARIA REINA	4,276	5,055	384	100	16	8

Panamax	9193317	AMSTERDAM EXPRESS	54,465	66,975	4.890	294	32	16
Post-Panamax	9305570	ZIM SHANGHAI	109,149	107,526	9.500	350	43	12

Note. Length, Beam and Draft measured in meters. Vessels have been randomly chosen based on their sizes. Source: (https://www.vesselfinder.com/vessels, https://www.marinetraffic.com, 2024).

Table B8. Suez and Panama Canals Fees and Strait of Magellan Pilotage Fees for Crude Oil Tankers

Choke Point	BEI HAI QI LIN	NORDPENGUIN	AEGEAN
Suez Canal	$ 325,100	$ 431,107	$ 822,103
Panama Canal	$ 215,328	$ 215,328	$ 215,328
Strait of Magellan	$ 28,261	$ 37,683	$ 86,879

Note. Fees calculated with tolls mentioned in Chapter (4.2). Source: (https://lethagencies.com/suez-calculator, https://serviceportal.pancanal.com/quote, https://www.directemar.cl/directemar/pilotage-fees).

Table B9. Suez and Panama Canals Fees and Strait of Magellan Pilotage Fees for Dry Bulk Carriers

Choke Point	ASIA STAR	SEAEAGLE	CAPE ASTRA
Suez Canal	$ 257,216	$ 294,827	$ 446,470
Panama Canal	$ 123,880	$ 123,880	$ 215,328
Strait of Magellan	$ 20,935	$ 25,122	$ 52,337

Note. Fees calculated with tolls mentioned in Chapter (4.2). Source: (https://lethagencies.com/suez-calculator, https://serviceportal.pancanal.com/quote, https://www.directemar.cl/directemar/pilotage-fees).

Table B10. Suez and Panama Canals Fees and Strait of Magellan Pilotage Fees for Container Ships

Choke Point	MARIA REINA	AMSTERDAM EXPRESS	ZIM SHANGHAI
Suez Canal	$ 20,899	$ 268,720	$ 430,907
Panama Canal	$ 43,035	$ 213,690	$ 215,328
Strait of Magellan	$ 8,949	$ 40,823	$ 61,757

Note. Fees calculated with tolls mentioned in Chapter (4.2). Source: (https://lethagencies.com/suez-calculator, https://serviceportal.pancanal.com/quote, https://www.directemar.cl/directemar/pilotage-fees).

Table B11. Average Fee

Vessel	Suez Canal	Panama Canal	Strait of Magellan

Crude Oil Tanker	$ 526,103	$ 215,328	$ 50,941
Dry Bulk Carrier	$ 332,837	$ 154,363	$ 32,798
Container Ship	$ 240,075	$ 157,351	$ 37,176

Note. Average fee from tables B8, B9, B10. Source: author's calculation.

Appendix C

This appendix aims to show the descriptive statistics for the variables of the augmented gravity model (9).

Table C1. Descriptive statistics for variables in Model 1

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Trade Flow	108	2.63e+10	.8.63e+10	747,203	5,59e+11
GDP America	108	6.60e+12	1.11e+13	1.17e+11	2,57e+13
GDP Europe	108	1.32e+12	1.38e+12	1.84e+10	4,09e+12
Population America	108	1.01e+08	1.35e+08	1.80e+07	3,33e+08
Population Europe	108	1.95e+07	2.42e+07	382,003	8,38e+07
ΔTransport Costs	108	-560,231	329,121	-1,069,835	23,311
ΔSeadistance	108	-3,800	1,726	-6,474	-740

Table C2. Descriptive statistics for variables in Model 2

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Trade Flow	108	2.63e+101	.8.63e+10	747,203	5.59e+11
GDP America	108	6.60e+12	1.11e+13	1.17e+11	2.57e+13
GDP Europe	108	1.32e+12	1.38e+12	1.84e+10	4.09e+12
Population America	108	1.01e+08	1.35e+08	1.80e+07	3.33e+08
Population Europe	108	1.95e+07	2.42e+07	382,003	8.38e+07
ΔTransport Costs	108	-525,812	316,965	-951,597	41,080
ΔSeadistance	108	-3,972	1,746	-6,772	-914

Table C3. Descriptive statistics for variables in Model 3

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Trade Flow	270	5.46e+09	1.91e+10	0	2.28e+11
GDP Asia	270	4.35e+13	1.22e+14	3.74e11	4.08e+14
GDP Europe	270	7.24e+11	1.05e+12	1.84e+10	4.09e+12
Population Asia	270	3.37e+08	5.46e+08	407,965	1.42e+09
Population Europe	270	1.95e+07	2.42e+07	382,003	8.38e+07
ΔTransport Costs	270	-358,712	131,771	-755,579	61,697
ΔSeadistance	270	-4,154	1,237	-6,757	-1,101