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[Bachelorarbeit]

[Exploring the impact of the Panama Canal expansion through game theory]

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List of abbreviations

- TEU = Twenty-foot equivalent unit, a standard container with a length of 20'
- CO_2 = Carbon dioxide
- LNG = Liquefied natural gas
- WTO = World Trade Organization
- GT = Game Theory
- ACP = Panama Canal Authority
- GHG = greenhouse gas
- IMO = International Maritime Organization
- SV = Shapley value

1 Abstract

The expansion of the Panama Canal in 2016 marked a significant milestone, enabling the passage of larger vessels and reshaping global trade routes. This expansion has not only altered the calculations of market actors involved in shipping but also empowered the canal authorities to reconsider transit fares. To analyze the implications of this expansion, this thesis explores the intersection of the Panama Canal expansion and game theory within the shipping industry literature. The objective of this research is to evaluate the extent of coverage of the Panama Canal expansion and the game theory approaches used in existing literature. The aim is to shed light on the impact of the expansion on the shipping industry. The thesis focuses on the analysis of a paper that used game theory to examine the impact of the Panama Canal expansion. According to the game theory model, the expansion caused a shift of market power from the US West Coast to the East Coast. In addition, the thesis will review and apply the findings of various related literature to the Panama Canal expansion. This thesis intends to contribute to a better understanding of the evolving role of the Panama Canal in the global shipping industry through an in-depth review of relevant literature and analysis of game theory applications.

2 Introduction

The Panama Canal is a widely discussed topic in literature, due to its unique position in connecting the Atlantic and Pacific Oceans. In 2016, an expansion of the canal was completed, allowing larger ships to pass through. This has led to a change in the calculations for many market actors involved in shipping goods through the canal and the surrounding regions. Generally, the size of container ships and the possibilities to employ them had been limited by the size of canals and the depth of ports(Cullinane and Khanna 2000). However, larger and more efficient ships can now take the shortcut through the canal, changing the calculation for alternative routes such as the Horn route around South America or the land route across North America by train.

The expansion of the Panama Canal has made it more attractive and has given more power to the authorities in charge of the canal. As a result, the factors they consider the transit fares have changed(Pagano et al. 2012). These changes in the market may have an impact on the overall market dynamics and require closer examination. To analyze the current situation of the Panama Canal expansion, Game Theory is a tool that can help understand the interactions between different actors, where the outcome of one actor may depend on the actions of another. It is an often used tool in research when analyzing the shipping industry.

The main focus of this thesis is to investigate the coverage of the Panama Canal expansion and game theory approaches in the shipping industry literature. Additionally, it aims to discuss the results in the context of the Panama Canal expansion and its impact on the shipping industry.

Examining literature about the expansion of the Panama Canal is crucial to acquiring knowledge, facilitating informed decision-making, and tackling the various complex challenges and possibilities linked to one of the most significant canals in the world. Examining research areas can aid in recognizing significant problems faced by the canal and discovering solutions for potential issues. This is particularly important considering the novelty of the current drought and the continuous challenges that the canal will face. Exploring further literature on the expansion of the Panama Canal can facilitate the evaluation of its economic ramifications, encompassing its consequences on trade routes, shipping arrangements, and local economies.

The thesis will be divided into several parts, each with a slightly different focus to answer the overarching question. Firstly, the thesis will provide theoretical background knowledge on the shipping industry. Then, it will delve into the historical significance of the Panama Canal, followed by an examination of its recent expansion. Next, an introduction to game theory will be provided, along with its relevant aspects to understand the later discussed research papers. After that, a specific paper analyzing the Panama Canal expansion with game theory will be reviewed. Following that, the thesis will examine a few different papers that examine the shipping industry through a game theory lens. It will explore how these applications may be applied to the Panama Canal expansion, and how the results can help understand the impact of the expansion. The thesis will also highlight any contradictions in the examined papers and how their findings might impact and support each other. Finally, the last part of the thesis will provide an overall conclusion and an outlook for future research.

3 Methodology

There are a number of good resources on the subject, but the search for reliable and specific sources has been difficult in some respects. Even though there is considerable research interest in the application of game theory, the large number of approaches that can investigate the shipping industry through a game theory lens resulted in some topics receiving a good amount of attention while other topics weren't significantly covered in the last few years. The specialization of the field also made it harder to judge the quality of papers on popularity metrics like citations and required a more qualitative approach to determine whether a paper was suitable for the review. I primarily used Google Scholar to locate and access articles for my review. I first used a combination of keywords such as: "Game Theory", "Panama Canal", "Expansion", "Shipping Industry", "Shipping" "Logistics", "Shapley Value", "Risk Assessment", "Quantifying Risk Taking", "Cooperation", "Algorithmic Game Theory", "Evolutionary Game Theory", "Climate Change", "Environmental Impact" to find useful sources. I also used ELICIT with the same keywords and additionally restricted results to articles from 2015 and onwards. Another tool I used was the website connectedpapers.com to visualize the connections between the papers and discover other articles of similar interest. While searching for papers and articles I paid special attention to several criteria when selecting my sources: the date of publication, how relevant the title is to the research question, the journal, and the research history of the authors. When I found a paper that covered the topics I was researching, I first read the abstract, introduction, and conclusion to determine if the topic of the paper was relevant to my literature review. While reading the paper I was continually looking for sources that the paper cited to find additional sources to include in my review and get a better grasp of the research covered in the paper.

When I was stuck, I utilized ChatGPT as a tool to generate new ideas and prompts. I would type in a word or phrase that I wanted to explore further and ask it for related keywords and their definitions. Finally, I used online tools to improve my writing, mainly Deepl and Grammarly.

4 Theoretical Background

4.1 Shipping Industry

4.1.1 Ships and Shippers

The shipping industry is concerned with transporting freight, especially by ship and is responsible for transporting a large amount of the world's trade, including goods such as oil, natural gas, and raw materials. Due to its importance to trade its developments receive worldwide attention by governments and industries (United Nations Conference on Trade and Development 2021). The primary part of the industry can be divided into several segments(Shi and Voß 2011):

- Liner shipping involves ships that run on a schedule. They have a fixed order in which they sail routes from port to port for cargo loading and unloading. More than 60% of the cargo transported via sea is carrying in liner services.
- Tramp shipping does not have a fixed schedule or a order of ports they sail to. They offer delivery service for specific demand.
- The Tanker business is similar to the tramp shipping but entails crude oil/oil product or bulk as cargo.
- The ferry business is about transporting passengers.

The different types of ships that transport goods can also be categorized:

- Container shipping entails the transport of standardized shipping containers.
- Dry bulk shipping involves the transport of unpackaged, dry goods such as grain, coal, and ore.
- Tanker shipping is about the transport of liquids, such as crude oil, petroleum products, and chemicals
- Specialized shipping is concerned with goods that require specialized handling or equipment, such as heavy machinery, vehicles, and livestock.

The industry has been heavily impacted by the COVID-19 pandemic, with disruptions in global supply chains and changes in consumer behavior leading to fluctuations in demand and shipping rates (Yazir et al. 2020). Overall the pandemic caused the main actors in the industry to face operational losses and inconvenience due to health and safety regulations. The restrictions and regulations that were introduced to combat the pandemic affected freight rates and, charter rates and earnings for the industry actors.
After the widespread adaption of containerization since the 1950, container transport has experienced very rapid growth and grew from 30 million TEUs in 1990 to over 140 million in 2020(*Review of Maritime Transport 2020* 2020). Carriers have adapted various forms of collaboration to handle this impressive growth.

4.1.2 Cooperation in the shipping industry

There are various forms of cooperation in the shipping industry. These can benefit different actors in the industry, such as shipping companies, ports and logistics providers. Some examples of cooperation in the shipping industry are:

Strategic alliances and Consortia: In recent years forming shipping alliances has been the most common practice among shipping fleets to further expand their business. Shipping alliance is a rather broad term and refers to multiple forms of cooperation. Shipping companies can form alliances with other companies to share resources such as vessels and terminals. They can also coordinate routes and pricing. These alliances can help companies gain market share and reduce costs through the cost advantages that companies gain from their size, achieving economies of scale. They can also improve their global reach, improve fleet utilization, and spread the risks associated with investment in large container vessels. The focus on strategic alliances enabled an additional pathway to success by creating a collaborative advantage as opposed to only relying on competitive advantage(Brandenburger and Nalebuff 2011). Through strategic alliances, shipping fleets seek to exploit the collaborative benefits that such an alliance brings. The drawbacks of entering a strategic alliance are mainly the increased regulatory and bureaucratic hurdles and loss of operational independence. Consortia are similar to alliances and are sometimes treated as one and the same, although consortia often focus on providing a single maritime service, while alliances tend to generalize and offer multiple services in relation to the shipping process. Consortia can enable companies to offer more frequent and reliable services, thus benefiting customers while reducing costs for the companies involved. Since the late 1990s and the intensification of globalization, strategic alliances, and consortia have developed to become the most widely used form of horizontal cooperation between shipping companies (Merk and Teodoro 2022). In recent years even the largest carriers that can benefit from economies of scale on their own have opted for alliance membership, but this trend has been broken by the announced discontinuation of the 2M alliance, which could signal a shift in the trend of alliance building in the shipping industry.

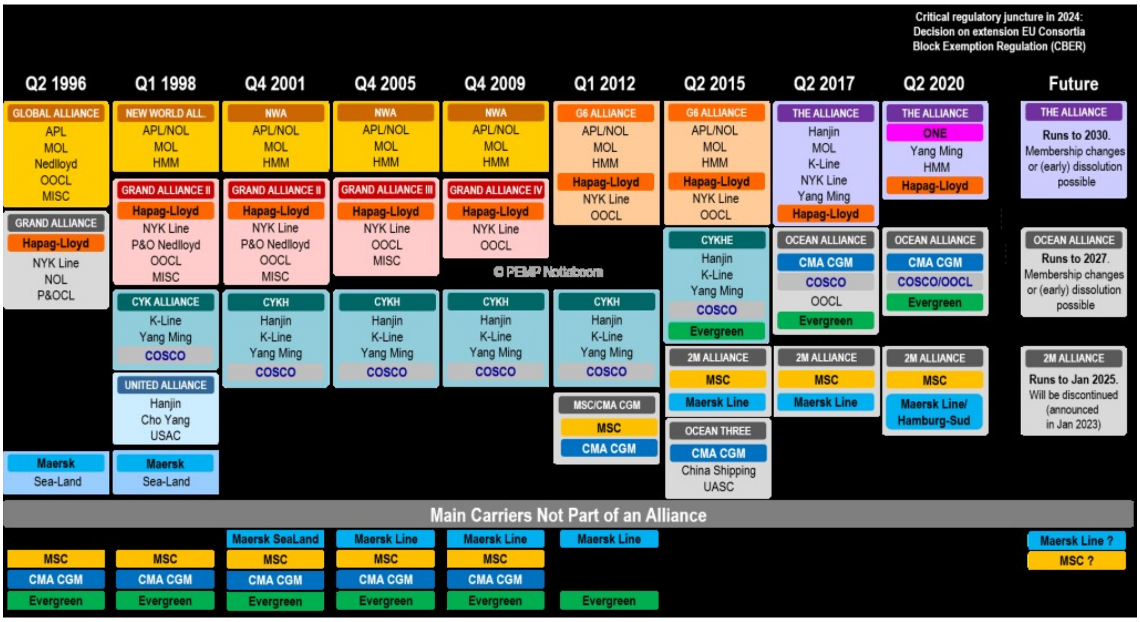

Figure 1: Alliances in container shipping

Source: *Alliances in Container Shipping* n.d.

Shipping alliances have gained popularity in recent times, but this trend has not been immune to criticism. Over the past 25 years, the market share of the top 20 carriers has almost doubled from 48% to 91%. Currently, the four largest carriers hold over half of the global container shipping capacity (*Review of maritime transport 2022* n.d.). Through integration, carriers and their alliances have gained stronger bargaining positions with port authorities, due to their dual roles as tenants of terminals and providers of shipping services.

Consolidation in the shipping market has reduced competition and limited supply. This can lead to abuse of market power, resulting in higher shipping costs for businesses and ultimately higher prices for consumers.

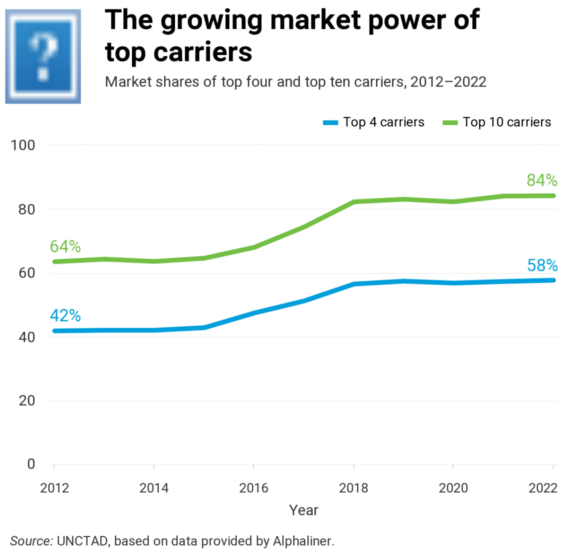

Figure 2: The growing market power of top carriers

Source: *Alliances in Container Shipping* n.d.

Joint ventures: Shipping companies may form joint ventures with other companies for the development of new infrastructure, such as ports, terminals, or for expansion into new markets. While sharing the risks and costs associated with new investments, joint ventures can provide companies with access to new resources and expertise.

Partnerships with ports: In order to improve efficiency and reduce costs, shipping companies can form partnerships with ports. For example, companies may work with ports to optimize cargo handling processes, reduce ship waiting times, or implement more sustainable practices.

Collaboration in shipping is characterized by a focus on mutual benefit, cost reduction, and taking advantage of economies of scale for all actors. Trust is essential because it requires a willingness to share resources and information and to work towards a common goal. The development of this trust has to be managed and properly incentivized to ensure the stability and longevity of the collaboration. Collaboration can also improve the overall competitiveness of the industry by helping companies adapt to changing market conditions and regulatory requirements.

4.1.3 Ports

Ports are vital parts of most nation's economies (Dwarakish and Salim 2015). A port is a place on the coast or shore that has one or more harbors. Ships can dock there to transfer people or cargo to or from land and they provide the platform on which shippers operate. Harbors can be either natural or artificial. An artificial harbor has purposely built breakwaters, while a natural harbor is naturally surrounded by land.

Ports play a vital role in the transportation industry, acting as a crucial point of connection between countries and the global economy. They enable the movement of goods and people across borders and serve as a gateway to integrate into the world's economic system. The major shipping lines are cooperating more and not only horizontal but also vertical cooperation is rising. As a consequence, ports have also started to become more cooperative (Mclaughlin and Fearon 2013). The traditional role of a port authority, for the benefit of its city region and wider hinterland community, has been to develop and maintain the infrastructure of its home port. However, this port area model is now changing. The dominance of one port within the supply chain is being reduced as terminal operators generally have more options and are able to choose between ports. This has led to strong rivalries between ports, as many seaports have responded by competing directly for the same containerized cargo flows. Port authorities must provide greater infrastructure and commercial incentives to retain major terminal operators. There has been a shift in the role of port authorities from being, in many cases, a dominant hub to being a facilitator in a logistics network between mainly private sector actors.

4.1.4 Ecological impact

The shipping industry, while being important for the global economy and for the time being the most energy-efficient form of freight transport, is one of the major emitters of greenhouse gas(GHG). While it currently is only responsible for ca. 2% of global emissions (Cames et al. 2015), without appropriate measures emissions could increase by up to 250% due to increased freight demands. As a consequence, the share of global emissions could increase to 17% by 2050.

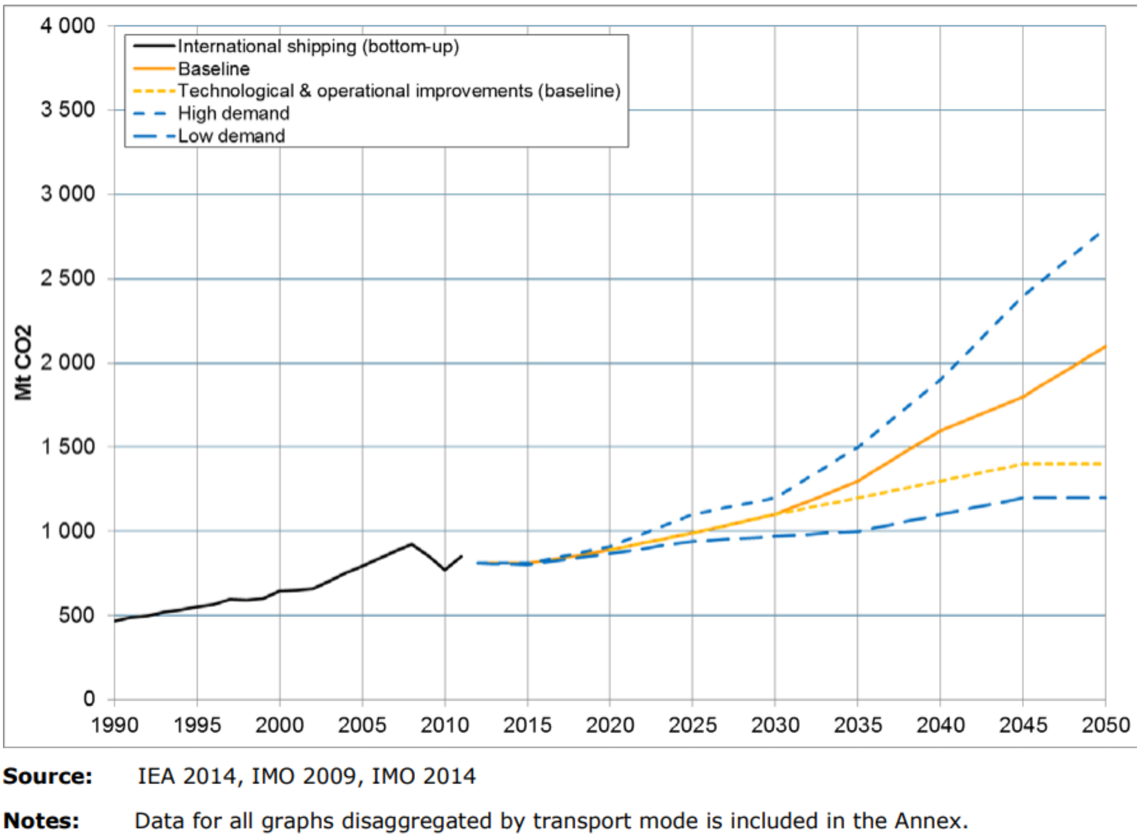

Figure 3: IMO projections of CO2 emissions from international maritime transport

Source: Cames et al. 2015

The task of regulating the emissions by container fleets is the responsibility of the International Maritime Organization(IMO). The IMO is the specialized agency of the United Nations with responsibility for the safety and security of shipping and for the prevention of pollution of the sea and the atmosphere by ships (*International Maritime Organization* n.d.).

The IMO has implemented regulations to reduce the industry's environmental impact. For example, the IMO's MARPOL Convention aims to prevent pollution from ships. It regulates the discharge of harmful substances. The IMO has also adopted the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). These are designed to encourage the development of more energy-efficient ships.

Another measure introduced is slow steaming, which is expected to have a huge impact on reducing fuel consumption and emissions. Slow steaming reduces the speed of a ship by 10-20%. This results in a corresponding reduction in fuel consumption and emissions.

To reduce greenhouse gas emissions from ships, alternative fuels such as liquefied natural gas (LNG), hydrogen, and bio-fuels are being explored. LNG, for example, emits less sulfur dioxide and particulate matter than traditional fuels. The industry is still introducing new ways to effectively police CO^2 emissions (Wan et al. 2018), and if it wants to contribute to the worldwide effort to combat global warming, deep emission reductions are still necessary.

Noise and vibrations from shipping can affect marine life, particularly whales and dolphins, and the construction of ports and shipping lanes can have a negative impact on marine biodiversity and disturb important habitats. Ships can also transport invasive species, which can cause significant damage to local ecosystems.

Overall, the environmental impact of the shipping industry is significant and there is a need for concerted efforts to reduce the industry's environmental footprint. These impacts can be handled by introducing measures such as improving fuel efficiency, investing in cleaner fuels, and developing sustainable shipping practices.

4.1.5 Future outlook for the shipping industry

The recent years in the shipping industry and especially the coronavirus pandemic have highlighted some major vulnerabilities (*Review of maritime transport 2022* n.d.) and authorities like the UNCTAD see the need for the shipping industry to improve their resistance to future crises.

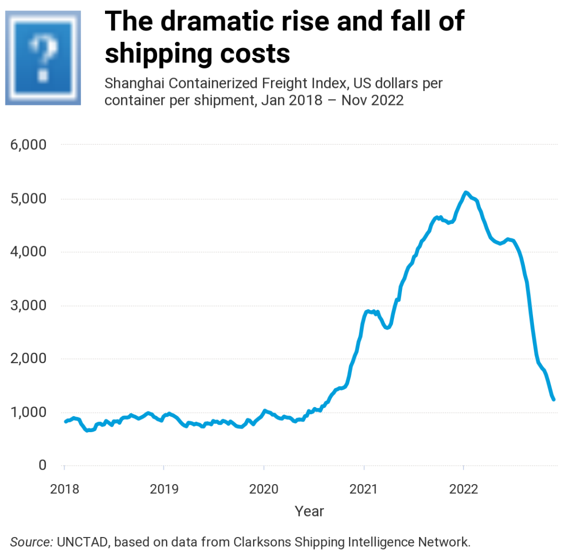

Figure 4: Change in shipping cost, Shanghai

Source: *Review of maritime transport 2022* n.d.

During 2021, the cost of shipping containers increased up to five times more than before the pandemic. This was due to disruptions in the supply chain, logistics limitations caused by the pandemic, and an increase in online consumer spending. As a consequence, prices for various goods also rose sharply, and the peak of container shipping costs occurred in early 2022. Even though these freight rates have fallen since they still remain above pre-pandemic levels and have showcased areas that need improvement for more stability in the shipping industry.

For that, the UNCTAD calls for(*Review of maritime transport 2022* n.d.):

1. "Governments and operators to expand and upgrade port infrastructure and land transport connections, and accelerate trade facilitation reforms, especially digitalization."

2. "Port operators and shipping companies to invest in increasing storage facilities and reducing equipment shortages."

3. "Shipping companies to invest in sustainable shipping and deploy the necessary ship-carrying capacity."

4.2 The Panama Canal

4.2.1 Historical Significance of the Canal

The Panama Canal is one of the most significant architectural achievements of the 20th century and had a massive impact on global trade and transportation. It has a length of ca. 50 miles and connects the Atlantic with the Pacific Ocean (Wilson and Ho 2018) through Lake Gatun. The ships enter through the locks and are elevated to the height of Lake Gatun. There, depending on the traffic, they wait until a slot opens so they can pass through a second set of locks to get down to the other ocean.

The construction of the PC started in 1904 and was finished in 1914. Many of its aspects were controlled by the U.S. Congress until 1999, when most of the control was given to the Government of Panama, which now manages its operation. Officially, today the canal is managed by an autonomous legal entity, the Panama Canal Authority(ACP)

Before the completion of the canal, maritime routes went along the much longer and more dangerous route around the horn of South America through the Drake Passage. The canals' completion reduced travel time between the Pacific and Atlantic oceans and made traveling much safer. This connection provided the east and west coasts of America, Europe, and Asia with more efficient routes. In the beginning transport from the east to west coast of America and vice versa utilized the canal the most. After 1952 Asia to the east coast of America became the route utilizing the canal the most. Shipments through the canal increased after containerization and the increase with eastern nations, first Japan and later especially China.

The canal had a big economic impact especially because of developments like these and enabled the movement of a lot of goods in the global supply chain. Countries in South and Central America enjoy greater access to global markets thanks to the canal.

On average the original canal manages to do about 40 transits per day, but that depends heavily on vessel types and sizes and can range from 28 to 42 transits a day. Ships in transit often stay overnight in Lake Gatun.

The impact of the canal on the shipping industry changed the global trading patterns and decision-making of a lot of the big players in the industry. The Panama Canal introduced size restrictions, introducing limitations in daft, beam, and length for the ships. It is the namesake of the "Panamax" ship size which for a time was one the most common ship types of the world. For the Panama economy, the canal is a major source of revenue and earns billions of dollars every year in transit fees. It is also a major source of tourism for the country and a lot of tourist facilities were developed to accommodate the canal as a tourist attraction. Due to that and the need for labor while operating the canal, it created and still creates a lot of employment in Panama. It also elevates Panama's role because it makes it a key strategic and logistic hub. A lot of international companies have operations in Panama because of the canal and it has attracted a lot of investment.

In conclusion, the Panama Canal has had a profound impact on global trade and transportation, transforming the shipping industry and facilitating the movement of goods around the world. The canal has contributed significantly to the economic growth of many countries, particularly those in Central and South America, and has enabled Panama to become a critical logistics hub. The Panama Canal's impact on the world economy remains significant and enduring to this day.

4.2.2 The Panama Canal Expansion

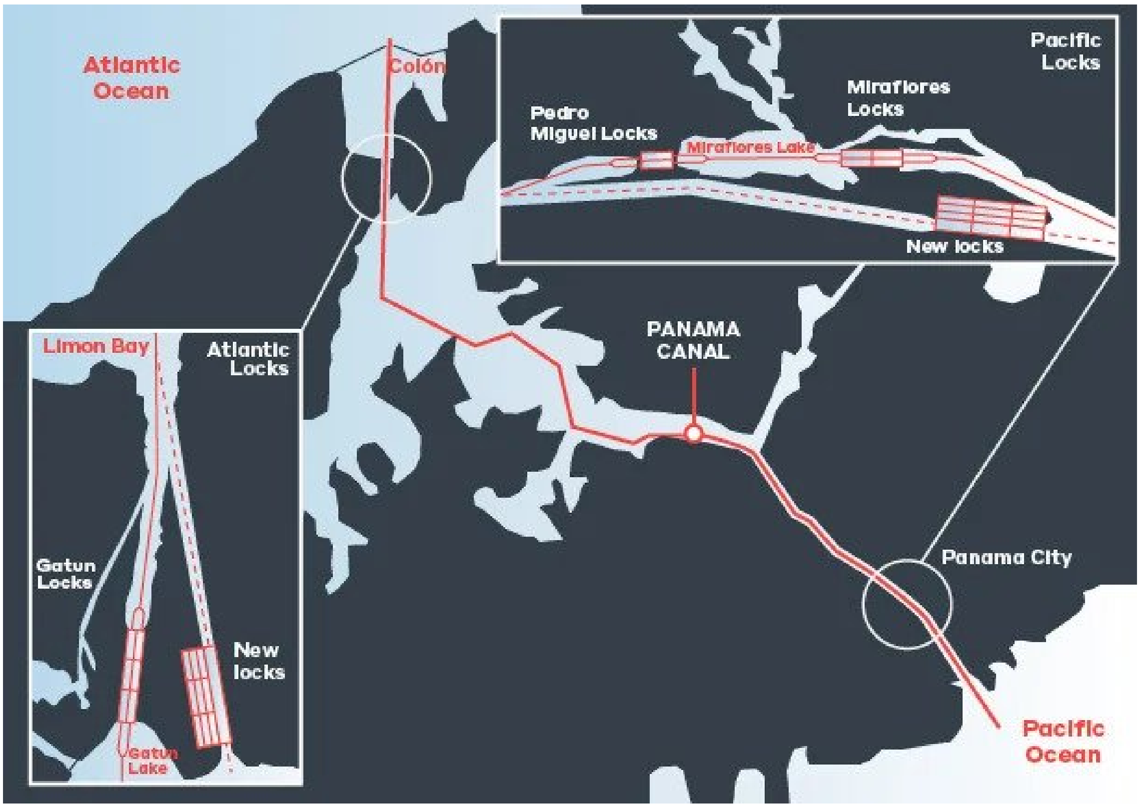

Figure 5: The expanded Panama Canal

Source: from: https://www.wsp.com/en-hk/projects/panama-canal-expansion

The Panama Canal Authority decided in 2006 to invest more than $5 billion into the expansion of the canal to focus on the future shipping market. The canal was expanded by building a third set of bigger locks that allowed the passage of larger ships. Two new locks, one on the Atlantic and one on the Pacific side were built and connected through channels and Lake Gatun. This changes the maximum ship size that can pass through the Panama Canal from "Panamax" to a new ship type "NeoPanamamx".

The expansion was done for several reasons. The trade with container ships and China was projected to grow and with it the projected demand for canal transit. The original canal was approaching capacity and was projected to be fully occupied by 2012. For that reason, queues for transiting the canal increased, and managing the traffic of ships wanting to cross the canal became more complicated. Further growth in demand beyond that would mean bigger problems in managing traffic and lost revenue when ships have to use alternative routes if the canal can't service them. In addition to that, trends in the shipping industry favor building larger ships. Newer container ship models are built in sizes exceeding the previous maximal size for ships using the PC which means that the majority of container ships and almost half of dry bulk ships wouldn't be able to use the canal. Furthermore, the competition in the shipping industry is intensifying. Shipments to the U.S., especially from Asia, are going more to the West Coast since alternative routes to the PC from Asia to the East Coast are less economically viable. The PC saves about 5200 nautical miles compared to the Suez Canal or the Cape of Good Hope route. There were even plans to open up a canal in Nicaragua that would be in direct competition with the Panama Canal, although this project has recently faced some setbacks due to the fact that the biggest investor has gone bankrupt.

Since the expansion didn't widen the old locks but built an entirely new set of locks for passage, the expanded canal now essentially offers an additional lane to cross Panama. It allows the transit of longer and wider ships and thanks to the modern construction mechanism also has a bigger capacity for transits per day.

4.2.3 Recent Developments of the canal

Recently the Panama Canal has been facing troubles in its operation because of a drought. In 2022 the canal processed a total of 14,239 transits, over 39 transits a day on average (*Panama Canal Statistics* n.d.). The operation of the canal requires huge amounts of water to fill the locks and the current weather conditions have forced the ACP to restrict the number of transits per day. Over the last few months, the number of daily slots was continuously reduced, first to 36, then to 32, and as of November 1st, to 31, with further cuts possible (*Panama Canal trims vessel passage quota again to deal with severe drought* n.d.). This has resulted in much longer than average waiting times for ships awaiting transit. As a measure to manage the decrease in the supply of transit, the ACP has mostly adhered to a booking system while employing an auction system to sell excess slots to waiting ships with prices having been reported to reach up to $2.4 million.

4.3 Game Theory

4.3.1 General Introduction

Game Theory studies mathematical and theoretical models of optimal decision-making when multiple players are involved in conflict situations, which distinguishes it from standard decision theory which normally involves a single decision-maker as its main focus, while game theory focuses on the interactivity of the decisions (Maschler, Zamir, and Solan 2020).
In essence, it is the field of interdependence in strategic decision-making, where actions don't only involve my outcome but the outcome of other actors and vice versa Spaniel 2014. It was first formally introduced by Von Neumann and Morgenstern 1947 in "Theory of Games and Economic Behavior". While at first it was mainly used to solve economic problems, later it was applied to a multitude of fields, for example in political science, psychology, and biology to model and predict behavior in situations of conflict and cooperation. The concepts developed in game theory have been and currently are being applied to many different real-world scenarios, such as international relations, bargaining, auction design, and others. For this thesis in particular its application in the fields of theoretical economics and networks is especially interesting. Game Theory in general tries to capture strategic behavior in different situations mathematically. It is constantly evolving, and newer concepts such as evolutionary game theory and mechanism design continue to refine and expand its applications. In game theory, a game is a situation in which the actors involved make strategic decisions. The actors are called players and the payoffs are numeric values that represent how desirable a possible outcome for a player is.

In game theoretic terms, players are the actors who are involved in making strategic decisions that affect the outcome. They can be a specific person, a group of people, or a more abstract entity like nature, a company, or a computer program (Von Stengel 2008). These players are assumed to have a number of particular attributes: rational, self-interested, and aware of the rules of the game. The number of players can range from two in a two-player game to an infinite number of players in some games.

4.3.2 Strategies and Payoffs

Strategies generally describe possible actions that a player can take. It can be a simple rule like always taking one particular action, or more complex so that the action of other players and the outcome is considered. Since the players are assumed to be rational, their strategies normally aim for profit/payoff maximization. Strategies can be dominant or dominated. It is called a dominant or a dominating strategy if it is always the better option compared to other strategies. If a strategy is always dominated by another strategy, it is always a worse option, we call it a strictly dominated strategy. A weakly dominant or weakly dominating strategy is one that is always at least as good as the other possible strategies, regardless of what the other players do. The opposite of this is a weakly dominant strategy. Players can play exclusively one strategy, which is called playing a pure strategy. Alternatively, players can mix their strategies, which means that they based on probability randomly play one of a set of strategies.

Payoffs are always the result of a game and often depend on the combined actions of the players. They are represented numerically and used to compare different outcomes. Players are assumed to be mostly or sometimes exclusively motivated by maximizing their payoffs.
Payoffs can be formulated in different ways. If we want to model reality in-game models, we have to choose the most suitable ways to assign payoffs to results. In some scenarios, we can simply directly use numerical values from reality. For example, if we are selling goods and have two offers of 2€ and 4€, we can simply assign 2 and 4 respectively as the payoff of the strategy of choosing the particular buyer. But that solution is only applicable to a limited range of scenarios. If we want to model the decision between going to a concert and going to the theater, that way of assigning payoffs doesn't work. Game theory has a significant branch that focuses on expected utility. The aim is to address the challenge of assigning appropriate payoffs to game outcomes. Typically, payoffs are ranked according to the player's preferred outcome, from the most to the least preferred. In that way, we can model almost all scenarios in game theory since the players are playing strategies for payoff maximization. As a result, the player should get the most preferred outcome possible in the game.

4.3.3 Games

Games are where players, strategies, and payoffs come together. Players each play a strategy, which results in a payoff for each player. A game is the collection of all payoffs for all possible strategy combinations of the players.

To represent a game and its strategic interactions in game theory, we need to characterize 3 basic elements(Gibbons 1992):

- the players, which in the context of the Panama Canal expansion would be shipping either fleets, shippers, the Panama Canal authorities and ports, or any combination of them for
- the strategies available to each player, which model the available courses of action for each actor. Depending on the game, new options can become available during or between iterations. For example, a PC expansion may unlock new courses of action for players.
- and the payoff each player receives for a combination of strategies of the players involved, which is meant to represent an often relative benefit for the player involved which can significantly change with the PC expansion.

For that, it is important to show who the relevant players are, what kinds of action are available to them, and what factors impact their decisions and by extension their payoffs to accurately describe a game model.

One of the most common games is the prisoner's dilemma:
The Prisoner's Dilemma is a classic example of a game that highlights the tension between individual self-interest and collective benefit, where cooperation can lead to a better outcome for both

players but may not be the dominant strategy.
Two thieves are caught and are interrogated in separate rooms. At the moment they are charged with trespassing, but the interrogators know they planned to rob a store. The thieves have several options:

- Both individuals confess, resulting in an 8-year jail sentence, which is reduced due to their cooperation.
- If one of the two individuals confesses while the other remains silent, the confessing party will receive a reduced sentence of only 1 year, while the one who chose to remain silent will receive a full sentence of 12 years for the crime of robbery.
- Both individuals stay silent, resulting in both receiving a full 3-year sentence for trespassing.

To illustrate games we construct matrices that condense everything we need to know.

		Thief 2	
		Remain Silent	Confess
Thief 1	Remain Silent	-3, -3	-12, -1
	Confess	-1, -12	-8, -8

Table 1: Prisoner's dilemma matrix

As we can see the matrix contains all possible payoff combinations. In these kinds of matrices, we see the strategies of Player 1 in the rows and the strategies of Player 2 in the columns. The first number in the payoffs belongs to Player 1 and the second to Player 2. When we examine the situation closer, it becomes apparent what the dilemma is. In this scenario, both thieves have two available strategies: to remain silent or to confess. The problem occurs when the individual thieves consider what the other player would do. Let's say Thief 1 is remaining silent. When we examine the payoffs we see that in that case thief 2 gets a payoff of -3 when she remains silent as well and a payoff of -1 if she confesses. Since Thief 2 as a rational player wants to maximize her payoff, she would always choose to confess. The situation is the same from the perspective of Thief 2 considering to confess. If we look at the situation that thief 1 is confessing, thief 2 gets a payoff of -12 if she remains silent and a payoff of -8 if she confesses as well. Again, as a rational player thief 2 would confess. This is precisely what we call a dominant strategy when the payoff of the strategy is always higher than the alternative, no matter which strategy the other player chooses. Strictly dominated strategies are never played without some kind of collaboration. Therefore, since both thieves have the same considerations, both thieves will always confess. That leads to the situation that the thieves will both receive a payoff of -8 even though they could have received a payoff of -3. This inefficiency is a the heart of game theory problems.
Games can be modeled in different ways for different considerations. Different types of games include simultaneous games, where players make decisions at the same time like the prisoner's dilemma, and sequential games, where players make decisions in a specific order Games can also account for different sets of information available to different players. We differentiate between imperfect and incomplete information. If it is a game of imperfect information players may be uninformed about the moves made by other players. Every one-shot, simultaneous move game is a game of imperfect information. In a game of incomplete information, players may be uninformed about certain characteristics of the game or of the players. Players may not know which move the other player made or they may be uncertain what the payoff for certain strategies for the other player is.

4.3.4 Equilibrium

An important concept in game theory is an Equilibrium, or often Nash equilibrium. A Nash equilibrium is a situation where each player's strategy is the best response to the strategies of all other players, and no player has an incentive to change their strategy unilaterally. The Confess-Confess situation from the prisoner's dilemma is a good example of a Nash equilibrium since no player can change their strategy on their own to improve their results. In consequence, no player does change their strategy and we can conclude that that is a reasonable outcome for a game. Depending on the type of game the concept of an equilibrium can change.

4.3.5 Cooperative Game Theory

When we look at normal or uncooperative game theory we face a problem: There are many scenarios such as the explained prisoner dilemma that face the problem that players can't reliably commit to an action which causes the game to end in a sub-optimal result. Cooperative game theory tries to solve that by making the assumption that players can in fact make that commitment, for example in the form of a legally binding contract. Players are then not viewed as individuals but rather as groups that have pooled their resources and have committed themselves to a collective form of action. This changes the focus from analyzing the interaction of the payoffs of individual players to examining how these commitments influence the overall situation and what outcomes that can lead to. Cooperative Game theory is especially important in the context of the shipping industry since coalitions between multiple Ocean Carriers are common and cooperative game theory offers good tools to analyze these alliances, for example, to decide how profit should be shared. An example of such a tool is the Shapley value, in the remainder of the paper abbreviated as SV. In general, it concept to fairly distribute the total value created by a group of players. It was introduced by Shapley 1951 in the early 1950s. In a cooperative game, a group of players work together to generate some total value, which can be divided among them in different ways. SV takes into account each player's contribution to the value and the order in which they make their contributions and provides a unique way of dividing the total value among the players. SV is based on the idea of marginal contributions. It calculates each player's marginal contribution, considering all possible orders in which players could have joined. The SV then averages the marginal contributions across all possible orders, giving each player a fair share of the coalition's total value.

4.3.6 Algorithmic Game Theory

Algorithmic Game Theory focuses on the computational aspects of games and their solutions. It combines ideas from Computer Science, Economics, and Mathematics to study strategic behavior in complex systems where outcomes still depend on the actions taken by multiple players.

Algorithmic game theory involves designing efficient algorithms that accurately solve complex games. That involves creating computational models that capture players' behaviors in games, analyze their strategic interactions, and identify optimal outcomes. This field includes mechanism design, algorithmic mechanism design, equilibrium computation, and the price of anarchy. Mechanism design is about designing game structures that incentivize players to behave in a desired way, particularly when players have different preferences or information. Algorithmic mechanism design involves designing algorithms that compute the best mechanism to solve a given game. Equilibrium computation involves finding the best strategies for players in games where multiple equilibria can arise. We have multiple libraries for popular programming languages that can help us set up and solve games quickly. The price of anarchy refers to measuring the inefficiency of equilibria that arise in selfish games where players optimize their own payoff without considering social welfare. Algorithmic Game Theory is used in many fields, including economics, computing, engineering, and social sciences. It has been applied to study topics such as network routing, resource allocation, online advertising, market design, and social networks.

4.3.7 Evolutionary Game Theory

Evolutionary game theory is a branch of game theory that studies how populations of players evolve through repeated interactions, and how this affects the dynamics of strategic behavior. In traditional game theory, players are assumed to be rational and self-interested. They have fixed strategies and preferences. Evolutionary game theory models players as biological organisms, with the ability to learn, adapt, and evolve their behavior over time through a process of natural selection. This is done by assuming that strategies that perform well in the current environment are more likely to be passed on to future generations of players. In evolutionary game theory, players' strategies are represented by genotypes or phenotypes. These can change through a process of mutation, recombination, and selection. The fitness of a strategy is determined by its performance in a given setting, and this fitness is used to determine which strategies will be passed on to future generations.

Some of the important concepts in Evolutionary Game Theory are:

- Evolutionarily Stable Strategies (ESS): Strategies that, once established in a population, cannot be overcome by a small group of individuals adopting other strategies (mutants). (Xiao and Yu 2006).
- Replicator Dynamics: A mathematical model that describes the evolution of strategies in a population over time, based on the principle that strategies with higher fitness will increase in frequency.
- Frequency-dependent selection: The idea that the fitness of a strategy depends not only on its absolute performance but also on its frequency in the population.

4.3.8 Criticisms of Game Theory

At its essence game theory is an abstraction of reality to fit it into a formal model. An essential limit of game theory is that it is desirable to include as many parameters as possible, but at the same time keep the model simple enough to be solvable. Additionally, game theory makes assumptions about certain conditions. Players are modeled as rational and utility maximizing, but humans have their own individual interests and might not always act completely rationally and make long-term decisions. This factor is mitigated by focusing on large groups of people like the shipping companies are. Since they are primarily profit-oriented, their behavior is less erratic and more utility-maximizing. Still, irrationality can't be completely excluded as a factor in why these models will have flaws. GT is generally very focused on rational decision-making and may not be well suited to model situations that depend on emotions and other factors that diverge behavior from strict rationality.

GT generally is also in question due to a lack of empirical support. Testing game theoretical approaches in the real world is oftentimes very challenging. Most of the time the complexity of the real world is unsuited to be completely translated into a game theory and it is even undesirable to do so since GT is used as a tool to handle complexity through the abstraction of reality and focusing on the important parts. While small-scale experiments validate some of the theory, it is still in question whether large-scale theories about the interactions of for example countries are really well explained through GT. And even if the models are accurate, in some contexts the results of game theory may not be desirable to apply in the real world fur to concerns from social welfare and ethical standpoints.

Overall, it is important to recognize the limitations of game theory and to be aware of the assumptions and simplifications that underlie its models, although it has proven to be a useful tool for analyzing strategic behavior in many different areas.

5 Research on the application of game theory to the Panama Canal expansion

The Panama Canal expansion has been explored through game theory in past literature. Liu, Wilson, and Luo 2016 estimated the impact of the Panama Canal expansion by modeling shipping goods from Hong Kong to the USA East Coast, Norfolk. That route is a good example of a lot of shipments that were impacted by the Panama Canal expansion. There are two choices: Use the east coast route through the Panama Canal and go entirely by ship or use the west coast route with a ship for transport to the USA west coast and cover the rest by train. Even if West Coast importers reduce prices for rail transportation, high inland transport costs make it difficult to compete with the advantages of the East Coast. The recent expansion of the Panama Canal now allows larger container ships to pass through, making it possible for more efficient ships to be used for transportation on the East Coast route. This even allows the East Coast route importers to increase margins while still maintaining an advantage. It was argued that excessive price hikes for transit through the Panama Canal could cancel out the benefits of its expansion.

The study's conclusion is that importers on the East Coast would have an advantage and gain market share, while those on the West Coast would lose out. When utilizing 8000-TEU container ships, the preferred route is the East Coast.

This approach can be further examined by involving the ACP as a player and taking into account how their incentives change based on the change in market dynamics.

Park, Richardson, and Park 2020 and Pham, Kim, and Yeo 2018 findings support these results with their more empirical approach. Pham, Kim, and Yeo 2018 compared the Panama, Suez, and US intermodal routes, and first identified the factors that influence route selection. They then used fuzzy theory which involves categorizing something as a degree of truth, rather than a strict true or false. This theory uses for example an interval between 1 and 0, instead of just 1 or 0. Finally, a multi-criteria decision-making technique was employed to assess the criteria and the available route alternatives. They find that transportation cost is the most important factor in route selection, followed by transportation time, reliability, and route characteristics. The preferred route is the route through the Panama Canal, surpassing the Suez and U.S. intermodal options.

Carral et al. 2018 did a statistical examination on how the Panama Canal will impact ship sizes and found that container transport will take up over 60% of the total traffic for the expanded canal. They also support the idea that the Asia-America East Coast route gains competitive advantage. Due to gas exploitation in the US and demand in Asia, this route attracts a lot of LNG ships, making up over 30% of the remaining traffic. These ships are usually post-Panamax size, but a new type of vessel is being developed to take advantage of the larger Neopanamax canal size. Bulk and cruise ships, however, are unaffected and continue to use the Panamax size.

6 Game theory approaches to the shipping industry

The shipping industry is a complex network of relationships and problems that can be explored through game theory. I will explore various research approaches that can be used to investigate the Panama Canal expansion and its implications. Additionally, I will discuss the potential impact of the research findings in the context of the expansion.

6.1 Cooperative Behavior and Profit-Sharing in the Shipping Industry

In the shipping industry are a lot of scenarios of cooperation between players that are worth examining closely. Ghorbani et al. 2022 did a review of the literature on cooperation in the shipping industry. They examined the trend of large shipping companies switching from mergers and acquisitions to engaging in shipping alliances. Currently, ways to monitor shared risk among members and which benefits can be expected from Shipping Alliances are insufficient. They also recommend exploring more methods on how to share vessel expenses optimally. These are some of the aspects of Shipping alliances that are important to manage to ensure the survival of the alliance, others include profit distribution and stability management. In recent years game theory offered several approaches to improve current practices. Liu and Imai 2005 gave an overview of applying the SV to the management of shipping alliances. The SV can be used as a basis for profit sharing and distribution, and as a mechanism to decide about new member acceptance into the alliance. Han, Sun, and Si 2013 proposed a SV model that verified that such a model can reduce instability in alliances and can consider all contributions of members of the alliance. A problem of the SV when applying it when deciding about accepting a new member is that it just represents the increase to the total worth of the alliance, but not the potential losses it may cause to other members. It could be that the entry of a new member causes disproportional loss to some members of the alliance even though it overall improves the alliance's competitiveness. Such a scenario could of course be undesirable for many reasons, for example, that it could cause the disproportionally hurt members to quit. To solve that they expanded on the concept of the SV and introduced the net value: it measures the impact of the entry on each individual firm and then summarizes that. A coalition is optimal if it consists of all members for whom the net value is non-negative; in other words, a coalition is optimal if it consists of all members whose entry causes the value of the coalition to increase so as to compensate all those who are made worse off. When analyzing alliance building with these mechanisms we see that larger shipping firms generally do not enter shipping alliances because they can rely on their own size and competitive advantages while smaller firms do enter these alliances to realize some of the benefits that the larger firms enjoy. There are many different proposed methods of profit sharing, Song and Panayides 2002 proposed a cooperative game theory concept based on the shipping capacity that the member provided to the alliance. However such a distribution, in many situations, was not guaranteed to provide a payoff that was enough to allow alliance members to continue collaborating. In extension Wang et al. 2016 applied the SV concretely to a profit-sharing scenario and how to apply them to members of different capacities. When applying the SV we must consider which factors should be included as contributions to the alliance. For shipping alliances, the most important factors that should decide how to distribute profit fairly in an alliance and have to be considered by a Shapley mechanism are risk-taking, market competitiveness, and investment in the alliance. The goal of implementing such a mechanism is to improve alliance stability and provide improved incentives for members. The profit share is a direct result of the members' ability and they can improve their share by improving their ability. This also introduces an interesting limitation, since quantifying factors such as risk-taking can be hard and it is necessary to identify appropriate methods to employ for the application in SV calculations.

When looking at SV methods to solve profit sharing in shipping alliances Guo et al. 2021 also examines SV as a suitable instrument to do it. But they apply the SV not only to the supplier side but also to the demand side. Normally when applying it in this context we consider the contributions to the alliance on the supply side, the risks and resource investments the alliance members take in relation to each other. In an industry that has close relationships with its customers, the customers should be an additional factor that measures alliance contribution. For that, we include the demand side in the form of customer satisfaction in the SV to try to increase to the accuracy of the SV in modeling the relative contributions of the members to the alliance. As a result, we were able to analyze alliances that include members of different sizes and, in contrast to previous methods, we found that smaller members with higher customer satisfaction receive a higher SV. This is in contrast to a scenario where only supply-side aspects are considered. Based on this, a conclusion can be drawn that bigger members should strive to increase customer satisfaction to better contribute to the alliance. Previously, this observation may not have been visible using the traditional methods. In general, the development of SV methods in alliance modeling focuses on adapting the calculation process to the shipping industry and identifying important factors to include as criteria when calculating the SV.

Jouida et al. 2021 uses cooperative game theory to test the establishment of coalitions. Specifically, it examines three different profit-sharing mechanisms: egalitarian allocation, proportional allocation, and SV. The results show that the formation of sub-coalitions is more likely than a grand coalition and that different sharing methods lead to different sub-coalitions. This study provides an experimental approach to model various profit-sharing mechanisms in shipping alliances and demonstrates that the distribution mechanism affects the formation of different coalitions.

For the Expanded Panama Canal, this research has several potential implications. The need to explore methods for sharing vessel expenses optimally implies that the Panama Canal should consider offering flexible pricing structures that incentivize shipping companies to use the canal efficiently. This could include discounts for higher volume usage, options for scheduling transit times, and adjustments to toll rates to optimize vessel expenses for alliance members. Applying the SV to both the supply and demand sides, taking into account customer satisfaction suggests that the Panama Canal should not only focus on satisfying shipping companies but also consider the needs and satisfaction of the end customers who rely on efficient shipping services. Similar to the examination of trends in shipping companies shifting from mergers and acquisitions to alliances, the Panama Canal authorities can analyze trends in the formation of alliances that utilize the canal's services and find ways to profit from such alliances.

6.2 Navigating the Future of Seaports and the Panama Canal

The logistics processes in modern seaports are undergoing a transformation due to digitalization. However, the success of this transformation relies on the adoption of advanced technologies and organizational structures. It is essential to align strategies and cooperate among stakeholders to achieve common goals for transforming port operations. To analyze options and costs, it is necessary to consider intra- and inter-organizational perspectives. A conceptual game theoretic framework proposed by Heilig, Lalla-Ruiz, and Voß 2017 aims to support strategic decision-making in seaports regarding cooperation formation. The framework connects game theoretic methods with collaborative strategies to create and evaluate various strategic coalitions of port actors. The framework is explained using the mobile cloud platform port-IO, which enables real-time information exchange and planning and management of inter-terminal transports in seaports. The Panama Canal is facing the challenge of digitalization, which is crucial to its continued operation. While most of the existing framework for intra-port cooperation is not applicable to the canal, the shipping industry is witnessing a rise in alliances and collaborations. Therefore, some of the approaches outlined in the framework can be utilized to improve cooperation between the canal and multiple shipping alliances. This will ensure a smoother coordination and better utilization of the limited transit spots available.

Effective digital transformation requires alignment among various stakeholders involved in canal operations, including government authorities, canal operators, shipping companies, and port terminals. Ensuring that everyone shares common goals and strategies is essential for the successful implementation of digital initiatives.

Given the limited transit spots available in the Panama Canal, optimizing capacity management is essential. Cooperation with shipping alliances can help in achieving better utilization of these spots by coordinating vessel schedules and transit plans. This can enhance the canal's throughput and reduce transit times.

Cui and Notteboom 2017 examine the impact of different privatization levels in competitive and cooperative games in ports. Three games were modeled: Cournot, Bertrand, and a cooperative game. The Cournot model involves players selecting quantities as a strategic variable in non-cooperative competition with other firms. In this model, the market determines the price of each good. On the other hand, in a Bertrand competition, which is our main focus, firms set prices and the market determines its demand for each type of good(Chan and Sircar 2015). The research found that the optimal private level of a partial public port varies between a fully private and a highly public-concerned port under Cournot and Bertrand competition. However, under the cooperation scenario, the government prefers a highly public-concerned port or one close to it, to maximize overall social welfare. In Bertrand competition, ports always produce higher environmental damage (ED) as compared to Cournot competition, as the optimal quantity in Cournot competition is lower. However, if ports collaborate and their services are less substitutable, they will generate the highest ED in the cooperation scenario. Moreover, when port operations are responsible for only a small share of total port emissions, the ED will be higher. In the monopolistic cooperation scenario, ports will have to pay more tax than the environmental damage they cause. This is not the case in Cournot and Bertrand competition sub-games. The game has shown that in order to get a private port to cooperate and improve overall social welfare, some form of compensation might be necessary. This has several implications for policymakers. The options explored are charging emission tax, making the port more private, or both. However, it should be noted that emission charges typically lead to a reduction in the volume of cargo handled by the port, due to the associated increase in costs. This, in turn, affects the profitability of both port operators and shipping lines. If the government sets a higher private level, the price of the service will tend to increase, resulting in lower volumes or capacity. This, in turn, lowers the optimal emission tax, which ultimately helps to increase profitability. It is important to note that charging an emission control tax and privatizing the port will always increase shippers' costs.

Corroborating these findings are Heejung 2015, which focused on examining the effects of private investment in container terminals. The findings suggest that private investment leads to improved performance, and restructuring of the terminal operator role also contributes to better performance. However, the paper also highlights the potential drawbacks of purely private investment, which could result in significant delays in infrastructure and equipment. As a solution for expanding port infrastructure, private investors could be useful in certain cases. They take however the view that the government should take over long-term plans to ensure steady development.

The research shows that the best level of privatization for a port can differ depending on the competitive dynamics. In the context of the Panama Canal, it is crucial to determine the optimal level of private-sector involvement. Policymakers and canal authorities should take into account factors like competition and cooperation with shipping companies to carefully consider the degree of private sector participation.

It has also been found that the type of competition can affect the amount of environmental damage caused by port operations. Bertrand competition results in higher levels of environmental damage compared to Cournot competition due to price competition. Since the Panama Canal is located in an ecologically sensitive area, the selection of competition models can have major environmental consequences.

Pujats, Golias, and Konur 2020 is a literature review of game theory approaches related to seaport cooperation, with a major focus on the port-side business. The review provides a brief summary of the methods used and the results obtained from 33 papers. The reviewed studies have identified some common patterns, including the fact that almost half of them involved some form of strategy to cooperate with ports and terminals. The studies on game theory approaches revealed that the Bertrand type of game was the most commonly used, accounting for 37% of all cases. Cournot came second with 29%, followed by Hotelling (20%), Stackelberg (12%), and Nash Bargaining (2%). Almost half of all games were modeled as two-stage games, followed by one-stage games, which accounted for a third of all models. The remaining games were three-stage games. The studies included horizontal and vertical relations between liners and ports, hub ports, and hub-spoke ports, including game theory network design. Increasing demand, mega-alliances, and larger vessels are some of the main factors that have shifted the growing demand for transportation and logistics. Contractors used to compete on price alone, but now they are differentiating themselves by providing better service levels. Common factors used to improve service levels include using more advanced technology and having stronger relationships with transportation providers. Ports and shipping companies are also investing in expanding their capacity to accommodate larger vessels.

The review indicates that nearly half of the studies involved cooperation with ports and terminals, suggesting that that is a common strategy in the industry. The Expanded Panama Canal can benefit from strategic partnerships with shipping companies and port operators to attract more vessel traffic and enhance its competitiveness. The transportation and logistics industry is shaped by increasing demand, mega-alliances, and larger vessels, indicating the need for efficient and larger-scale transportation solutions. The ACP should adapt to these trends to remain a vital part of global trade routes. The review also indicates that contractors in the shipping industry no longer compete based solely on price. Instead, they prioritize providing better service levels. To attract shipping companies and cargo traffic, the Expanded Panama Canal should devise strategies to improve service quality, such as enhancing transit times, reliability, and overall customer experience. Successful digitalization management, as discussed earlier in this chapter, is a vital pathway towards achieving this goal.

6.3 Insights from Algorithmic Game Theory and Optimization

Lin, Huang, and Ng 2017 examines shipping alliances by framing them as a coopetition, a cooperation where the members internally compete for benefits. The model assumes that several carriers in the freight market cooperate and compete, with each carrier having the means to satisfy customers' transport demands. The market demand is composed of the initial preexisting demand and demand induced by the carriers' action, with the latter coming from customers originally serviced by carriers from other alliances.

The Game Theory model assumes that carriers are equally competitive and that there is no leader or follower. It is modeled as an extensive form game, with two stages: cooperation to decrease average costs and increase total market profit, and simultaneous competitive effort to increase the carrier's own profit. Carriers have perfect information on cooperative investment and price competition strategies in the market and the game is static, with carriers' decisions not changing over time.

In this scenario, two carriers, each with its own network, compete and cooperate to meet market demand. Carrier A solves its optimization problem, affecting market price and costs. Carrier B decides its best strategy, forming an iterative two-stage coopetition game. Each carrier adjusts its strategy based on other players' decisions until no carrier can benefit from unilateral changes. The author showed in Lin and Huang 2013 that diagonalization methods can be used to solve this problem. They first address a single-carrier optimization problem. This is done by assuming that the decisions of all other firms for this carrier are already fixed. Once they have the results of this optimization problem, they use them as external data for the calculations of the second carrier. Similarly to the first carrier, the second carrier's optimization problem is solved under the same assumption. This process is repeated until all carriers cannot improve the objective value by unilaterally changing their decisions. This iterative approach is made possible by using computing power.

The study found that apart from the competition level, a carrier's profit can be influenced by various other factors. Empirical research indicates that carriers tend to select comparable levels of coopetition to optimize their profit. Furthermore, under general conditions, the coopetition game can reach equilibrium. The cost of competition may affect the competition level, and the cost of cooperation may impact both the cooperation and competition levels.

Wang, Meng, and Zhang 2014 also examine the competitive behaviors between two container carriers in the liner shipping market, focusing on combined market strategies including freight rate and shipping deployment. Three game models – Nash game, Stackelberg game, and deterrence game – are proposed to characterize different competitive behaviors. The study discusses the existence of Nash equilibrium with discrete pure strategy and develops a numerical solution algorithm to determine the approximate Nash equilibrium with minimal approximation. The application tests show that expanding ship capacity is more economical than updating frequency for service capacity provision. The computational efficiency analysis shows that the developed solution algorithm efficiently solves the -approximate Nash equilibrium.

Both papers assume a certain demand for their models and identify the exploration of the questions under uncertain demand as interesting future research questions.

Just as the research examines shipping alliances as "coopetition," one can apply this concept to understand how alliances between shipping companies and other stakeholders in the Panama Canal ecosystem (e.g., terminal operators, logistics providers) cooperate and compete for benefits. Analyzing these dynamics can provide insights into how to optimize canal operations and resources.

The research discusses the composition of market demand, considering both preexisting demand and demand induced by carriers' actions. This concept can be applied to analyze the demand for the Panama Canal services, taking into account factors such as global trade trends, regional economic activities, and shipping route preferences.

The iterative approach used in the research to find equilibrium solutions in coopetition games can be applied to optimize the allocation of canal resources and infrastructure development. For example, determining the optimal usage of canal locks or scheduling transit times for different vessels can be treated as iterative optimization problems.

The study mentioned in Wang, Meng, and Zhang 2014 suggests that expanding ship capacity may be more economical than increasing frequency for service capacity provision. This finding can be relevant to the Panama Canal when considering infrastructure expansion projects. It may influence decisions on whether to invest in larger locks or other capacity-enhancing measures.

6.4 Environmental Considerations

Lin, Juan, and Ng 2021 established an evolutionary game theory model with the following premises: the players are a population of shipping lines that are randomly selected to compete with each other. They each have two strategies available: "green" or "no-green". As a result, there are three scenarios that determine the payoffs: Scenario 1 where both players choose a green strategy, Scenario 2 where both choose a "no-green" strategy and Scenario 3 where one chooses the "green" strategy" and the other the "no-green" strategy. Most of the population will ultimately adopt the strategy with a better-than-expected payoff as a result of the game. After analyzing the payoff function under three scenarios, the study concluded that the green strategy is an evolutionarily stable strategy with an adoption rate of 89.74%. While Scenario 1 results in the highest prices, followed by Scenario 3 and then Scenario 2, it also results in the biggest payoff which shows that shipping lines that prioritize environmental concerns can achieve higher payoffs than those that prioritize maximizing payoffs in a green market. Pujari 2006 and Li et al. 2016 similarly found that "green" strategies can generate a competitive advantage for the entire supply chain stakeholders.

The IMO has been implementing stricter regulations to reduce pollution and greenhouse gas emissions, primarily focusing on SO^2 emissions. Jiang and Zhao 2022 examines the impact of IMO sulfur limits on SO^2 and CO^2 emissions from a game theory perspective and provides insights for regulators. The study found that optimal sailing speeds are determined by fuel prices, with higher HSF prices leading to slower speeds. However, the new Global Shipping System (GSC) implemented by the IMO in 2020 does not always reduce SO2 and CO2 emissions. The study suggests that IMO sulfur limits may not decrease SO2 and CO2 emissions, as fuel prices play a crucial role in determining optimal vessel speeds and environmental consequences. The IMO should impose new measures to encourage shipping companies to improve energy efficiency or develop emission reduction technology to reduce CO2 emissions.

The papers I reviewed do not provide a direct analysis of the Panama Canal's contribution to climate change mitigation. Nonetheless, the recent events have brought to light the significance of adopting environmentally friendly practices in the efficient functioning of the Panama Canal. The research indicates that implementing appropriate incentives can facilitate the widespread adoption of green shipping strategies, which can result in sustainable and eco-friendly operations. By accommodating environmentally friendly vessels and supporting sustainable transportation options, the canal can attract more customers and increase its revenue. Lin, Juan, and Ng 2021 suggestion that "green" strategies will lead to the highest payoff also suggests that the Panama Canal can profit from this development by increasing prices while not majorly negatively impacting the "green" shipping operations. It is worth noting that the adoption of green shipping strategies aligns with the global agenda of mitigating climate change and promoting sustainable development. Therefore, it is of utmost importance for the Panama Canal to support these incentives and encourage the adoption of sustainable shipping practices, especially for its own self-interest.

Wan et al. 2018 focuses on the CO2 emissions of the shipping industry and analyses the measures taken to regulate it. They found that a performance-based index as a solution has loopholes affecting effective CO2 emission reduction driven by technological advancements. Using slow steaming to cut energy consumption stands out among all operational solutions thanks to its immediate and obvious results, but with the already slow speed in practice, this single source has limited emission reduction potential. Without a technology-savvy shipping industry, a market-based approach is essentially needed to address the environmental impact. To give shipping a 50:50 chance for contributing fairly and proportionately to keep global warming below 2 °C, deep emission reductions should occur soon. For that to happen binding international agreements to regulate GHG(greenhouse gas) are only evolving slowly, technical solutions remain expensive, and crucial industrial support is absent.

7 Limitations

One of the major limitations of this thesis is that it touches on the application of game theory in relation to the Panama Canal but fails to elaborate on any specific game theory models or methodologies that could be applied to the situation. More concrete examples of how game theory can be utilized to analyze the canal's dynamics are needed for a more in-depth exploration.

Another limitation is that the thesis offers general recommendations such as improving service quality and implementing dynamic pricing models. However, it does not provide a detailed roadmap or actionable steps for implementing these recommendations. It lacks specificity in terms of how these strategies can be executed which should be the target of future research,

The thesis mentions that different types of competition can have varying levels of impact on the environment, but it does not provide any specific environmental strategies or solutions that the Panama Canal authorities could implement to reduce such impacts. It would be helpful if future research could offer concrete suggestions for mitigating environmental damage caused by the canal operations.

8 Conclusion

The goal of this thesis was to explore the current state of research of game theory applications in the shipping industry and apply some of these methods to the Panama Canal situation. The reviewed literature delivers several key insights in relation to the Panama Canal expansion:

Importers on the East Coast gain a competitive advantage with larger vessels now crossing the Panama Canal, while those on the West Coast may lose market share. That is while transportation cost is the most critical factor in route selection, followed by transportation time, reliability, and route characteristics.

The ACP should not only focus on satisfying shipping companies but also consider the needs and satisfaction of the end customers to further generate advantages when it comes to route selection. Panama Canal should devise strategies to improve service quality, such as enhancing transit times, reliability, and overall customer experience.

The authorities of the Panama Canal can study the trends in the creation of partnerships that use the canal's services and explore opportunities to benefit from these collaborative efforts. The Panama Canal can benefit from strategic partnerships with shipping companies and port operators to attract more vessel traffic Effective digital transformation necessitates alignment among canal operations' various stakeholders, which includes government authorities, canal operators, shipping firms, and port terminals. It is crucial to ensure everyone shares common objectives and strategies to implement digital initiatives successfully. Especially in light of that it is crucial to determine the optimal level of private-sector involvement. Policymakers and canal authorities should take into account factors like competition and cooperation with shipping companies to carefully consider the degree of private sector participation.

Panama Canal should consider implementing dynamic pricing models to encourage optimal usage by shipping companies. Optimizing capacity management is vital. Collaborating with shipping alliances can assist in achieving greater utilization of these locations by coordinating vessel schedules and transit plans. Especially in light of the recent shortages, optimal transit slot utilization becomes paramount.

For line shippers, expanding ship capacity is a more cost-efficient approach than increasing service frequency to enhance capacity provision which in light of resource usage is a thing that the government bodies may look into to disincentivize. The nature of competition can influence the level of ecological harm attributable to port activities.

Promoting environmentally-conscious shipping measures has the potential to generate supplementary revenue for the canal.

In this review, we have explored the ways in which game theory can help us understand the Panama Canal expansion. We have also discussed how game theory approaches from the shipping industry can be applied to the Panama Canal situation.

9 Recommendations

For further research, there are several areas that are recommended to explore in further detail:

The aspect of creating partnerships through the use of the canal's services is a worthwhile idea that needs further examination to propose concrete steps the ACP can take to engage in such partnerships.

As explored here digital transformation will also be a major challenge for the Panama Canal. It has distinct differences in incentives and strategies from normal ports and examining how port digitization strategies should be adjusted to be useful for the Panama Canal is a good further research direction.

The implementation of dynamic pricing models to incentivize optimal canal usage is a possibility. Such models could adapt to changing market conditions and shipping patterns, promoting efficient transit through the canal. Especially recently we have seen that the Panama Canal can be a victim of unforeseen circumstances that restrict capacity for the foreseeable future. A closer investigation of whether dynamic pricing can help mitigate the damage from these events should be the topic of further research.

Encouraging environmentally friendly shipping practices is especially in the ACP's interest in light of the recent drought. The Panama Canal may explore initiatives to reduce environmental impact, which could contribute to additional revenue streams while aligning with global sustainability goals and securing their continued operation.

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