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**GAME THEORY APPLICATIONS FOR SEAPORT  
COOPERATION, COMPETITION, AND CO-OPETITION**

**Final Report**

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## EXECUTIVE SUMMARY

Maritime transportation is a critical component of international trade with approximately 90% of the global trade volume carried by deep sea vessels (Journal of Commerce (JOC), 2014). The World Shipping Council (2014) indicates that “*it would require hundreds of freight aircraft, many miles of rail cars, and fleets of trucks to carry the goods that can fit on one large liner ship*”. According to the data provided by the United Nations Conference on Trade and Development (UNCTAD, 2015), the overall international seaborne trade reached 9.8 billion tons in 2014 with a significant increase of containerized (5.6% in tonnage), dry (2.4% in tonnage), and major bulk cargo (6.5% in tonnage) from 2013. Similar growth is expected to continue. Most of the high-value cargo and general consumer goods are shipped in a containerized form. Liner shipping companies, looking for transport efficiency and economies of scale, have increased vessel size on most of the trade routes. The Journal of Commerce (JOC), 2015 highlights that CMA CGM placed an order for six vessels with 14,000 TEU capacity in the first half of 2015 after an earlier order for three 20,000 TEU vessels. Maersk has recently ordered eleven 19,500 TEU vessels, while MOL and OOCL placed orders for vessels with 20,000 TEU capacity. Note that the number of megaships is projected to increase by at least 13% by 2020 (Journal of Commerce (JOC), 2015).

To meet the growing demand, while facing capacity expansion limitations (e.g., lack of land, high cost of expansion, etc.), marine container terminal operators and port authorities have emphasized the importance of planning and operations optimization as a means to increase productivity (see for example Forster and Bortfeldt, 2012; Golias et al., 2014; Luo et al., 2012; Mauri et al., 2016; Nguyen et al., 2013; Petering and Murty, 2009; Preston and Kozan, 2001). A terminal capacity can be increased by upgrading the existing or constructing the new infrastructure but requires a significant capital investment (Cordeau et al., 2004; Petering and Murty, 2009). Alternatives to the construction of the new infrastructure include improvement of conventional equipment and productivity by introducing new forms of technology (Dulebenets et al., 2015; Emde et al., 2014), information systems (Henesey, 2004), and work organization (Paixão and Bernard Marlow, 2003). One approach that can increase productivity without the capital investment is better utilization of the existing berthing capacity between terminal operators, ports or both through collaborative agreements (Canonaco et al., 2008; Cargo Business, 2014). One may view such agreements as the answer of port authorities and terminal operators to alliances, formed by liner shipping companies (Panayides and Wiedmer, 2011) that allow vessels from different liner shipping companies to be served at different terminals of the same or different ports (Journal of Commerce (JOC), 2016a; Journal of Commerce (JOC), 2016b; Journal of Commerce (JOC), 2017).

In this project, we investigate the applicability of game theory models (e.g., multi-objective, Bertrand/Nash equilibrium problems -with or without equilibrium constraints-, Nash Bargaining and Equilibrium, Stackelberg etc.) to model cooperation, competition, and co-opetition between marine container terminal operators (MCTOs), seaports, and liner shipping alliances. The objective is to develop a mathematical framework that will maximize port revenues, minimize

port costs and increase freight fluidity through our nation's seaports. With this research we build upon and expand on existing research by the PI and Co-PI (Karafa et al., 2011; Dulebenets et al., 2015) and others (e.g., Lee and Song, 2017; Parola et al., 2017; Heaver et al., 2001; Midoro and Pitto, 2000) and propose to develop game theory based mathematical, simulation models or both that will not only assist marine container terminal operators and port authorities in identifying optimal contractual agreements (for sharing capacity and with liner shipping companies) but will also identify optimal operational plans that support implementation of such contractual agreements (i.e., contractual agreements are usually based on total demand handled while operational plans are based on vessel assignment and terminal resource allocation at the operational level). To our knowledge, only four studies have been published to date that address the later component (Imai et al., 2008; Karafa et al., 2011; Dulebenets et al., 2015).



## 1.0 INTRODUCTION

The complex dynamics between seaports and shipping lines have only increased since the Great Recession in 2008. Since then, the shipping industry has experienced overcapacity, volatile freight rates and rising debts in the shipping industry, which ultimately lead to the bankruptcy of one of the shipping lines. To keep themselves above water shipping lines responded by engaging in shipping line alliances, integrating vertically with container terminals and increasing the size of vessels, thus reinforcing their market power in the shipping industry. These changes and others have resulted in an increasingly competitive environment in the port sector. This report will study competition, cooperation and co-opetition in the maritime shipping industry from the side of the port, by reviewing literature that models the interaction between ports, container terminals and other stockholders using game theory models.

Port and container terminals willingness to engage in cooperative agreements has become an emerging theme as now more ports are seeking new ways to increase their profit and bargaining power over shipping lines. Several studies reviewed in this report were seeking answer following questions: At what service levels should cooperation, competition or both take place to gain the most benefit? How the geographic location and different service levels for ports with overlapping hinterland affect port competition and cooperation? At what service levels public and private port authorities would engage in cooperation and competition? What are the effects of price setting between ports terminals in different coalition combinations? What cooperation policy would gain the most profit when container terminals share their available demand capacity?

Competition between ports has been well researched field with numerous studies searching to find answers to at what service levels when ports compete for transshipment cargo inter- and intra-port competition could be beneficial? How the introduction of fully dedicated terminals affects the intra- and inter-port competition between multi-user terminals? How concession award affects inter- and intra-port competition? How service levels affect port competition when there is a leader in a market? How port pricing affects the competition between ports in the transport and logistics network? How and when port capacity investment can increase market share in a competition setting between ports?

As it was with the shipping lines and ports the relationship between ports and governments has changed, having varying port ownership and regulation modes. Numerous authors have worked towards explaining the interactions between government, port and container terminals under competition and cooperation settings by raising the questions as follows: Under what circumstances which type of regulation mode is the most beneficial? In what settings should the government consider privatization of public ports to increase ports competitiveness? At what scenario competition or cooperation could be more beneficial when modeling the interaction between emission control and port privatization? How investment in port and common hinterland capacities and imposing congestion tolls affects port profit and hinterland congestion?

Following the restructuring of the liner shipping market and increased vertical integration between shipping lines and ports many authors have attempted to model the interaction between shipping lines and ports by seeking answers to following questions: How are the equilibrium port charges determined when ports compete or cooperate for the shipping lines container demand and transshipment demand? How cooperation or competition between hub ports, spoke ports or both could help capture greater market share from shipping line companies?

These and many more questions were asked by researchers with goal find the role of ports and container terminals in the ever-changing maritime shipping industry. The questions asked by researchers are complex and involve situations where there are multiple decision makers with different objectives, thankfully game theory allows us to study these questions from the strategic point of view, thus giving the ability predict the player behavior, which could potentially be used in a decision-making process.

The remainder of this report is organized as follows: Section 1 introduces the industry and gives a list of investigated questions from the reviewed literature Section 2 provides an up-to-date literature review is presented summarizing state of the art and practice on seaport, container terminals, and liner shipping networks operations and best practices at the planning, tactical, operations, and real-time horizons. Section 3 presents the conceptual and mathematical framework for the port, terminal operator and liner shipping alliance cooperation and competition using the Stackelberg game. Section 4 presents the syllabus for a one-day workshop on cooperation, competition, and co-opetition strategies at seaports developed specifically for this project. Section 5 concludes the study with some implications and suggestions for future research.

## **2.0 LITERATURE REVIEW**

In this section, an up-to-date literature review is presented summarizing state of the art and practice on seaport, container terminals, and liner shipping networks operations and best practices at the planning, tactical, operations, and real-time horizons. The literature review also summarizes game theory approaches that have been or could be applied to model cooperation, competition, and co-opetition in maritime transportation, strategic/tactical/operational pricing, and solution algorithms applicable to the game theory models identified in the literature. The rest of this section is structured by applied game theory models on a group of stakeholders as follows: Section 2.1 reviews literature on port and container terminal cooperation/competition and co-opetition, Section 2.2 reviews literature on port and container terminal competition, 2.3 reviews literature on government, port and container terminal competition/cooperation, 2.4 reviews literature on government, port and shipper's competition, 2.5 reviews literature on government, port and manufacturing firm competition, 2.6 reviews literature on port and liner shipping competition and cooperation, 2.7 reviews literature on ocean carrier, port terminal and land carrier competition.

### **2.1 PORT AND CONTAINER TERMINAL COOPERATION/ COMPETITION AND CO-OPETITION**

In this subsection, we review the literature on game theory approaches, factors and conditions affecting seaport, marine container terminal or both cooperation and competition. The effect of service level differentiation between two ports was investigated by (Wang et al., 2012), between three ports was investigated by (Ignatius et al., 2018). The service level differentiation with a combination of shipping distance investigated was examined by (Wang and Sun, 2017) and (Zhou, 2015). Port ownership and level of service differentiation on the capacity, service price, profits and welfare among competing or cooperating ports was investigated by (Cui and Notteboom, 2018). The effect of price setting in a container terminal coalitions at single ports was investigated by (Saeed and Larsen, 2010a), between two ports was (Park and Suh, 2015). The effect of sharing available demand and capacity between container terminals using four cooperation policies was investigated by (Pujats et al., 2018). These studies are summarized in Table 1. In the following section, we continue to discuss the port and container terminal cooperation and competition in a more detailed matter.

Factors and conditions affecting ports serving partially overlapping hinterlands where investigated by (Wang et al., 2012) using Cournot competition and joint profit maximization by developing a game theory model to reflect the institutional and political constraints ports face in real life. Results suggest that where institutional and political factors prohibit the usual business practices in alliance formation, such as the merger, cross-shareholding, and transfer payments, alliance formation becomes much less likely. Without the usual commercial arrangements to properly relocate the benefits of cooperation, a port alliance will be established only when there is a balance between the incentive to increase prices and to switch some of the throughput from

high-cost ports to low-cost ones, and thus all participating ports can benefit from the cooperation. Competition and cooperation between ports were investigated by (Ignatius et al., 2018), where authors applied Cournot competition and collusion between the three main transshipment ports located in Malaysia and Singapore: Port of Singapore (PSA), Port Klang (PKL), and Port of Tanjung Pelepas (PTP). Authors found that strategic alliance between PSA and PTP generates greater profitability to the current hub and spoke network, while PKL should not commit to any cooperative strategy with either PSA or PTP. Similarly, (Wang and Sun, 2017) investigated competition and cooperation among ports in the port group based on geographical location, and additionally, the service level and shipping distance were investigated using Hotelling game model. When the service level of port enterprises is the same, a cooperative strategy can significantly improve the level of the port group's profit. When the service level of port enterprises is different, service price of port, market share of port and port's profit are affected by the service level before and after the cooperation, the service level of port enterprise shows a trend of mutual promotion, and the port group develops into the higher service level. Price strategy of ports serving partially overlapping hinterland was investigated by (Zhou, 2015) where author used a modified Hotelling model analyzed the price strategy and simulation for three ports with competitive and cooperative targets. Research results revealed that, with the same service levels, location is a critical factor for competitive ports and since the locations of the ports are always fixed, the service levels will be the critical factor affecting alliance. Four types of two-stage games between public/private ports authorities were modeled by (Cui and Notteboom, 2018) to examine the effects of public/private port authorities-oriented objectives and the level of service differentiation on the capacity, service price, profits and welfare among competing or cooperating ports. Author concluded that under Cournot competition, both Port Authorities (PA) would be reluctant to cooperate by forming a strategic alliance unless the partial public PA will agree to transfer certain profits to the private PA as a compensation for joining the co-operation alliance. Under all other types of competitions, a PA with a highly private-oriented objective will be more motivated to cooperate with the private PA. In contrast, a PA with a highly public-oriented objective will show a much lower willingness to cooperate with a private PA under a similar setting.

Different combinations of coalitions between terminals at a single port were investigated by (Saeed and Larsen, 2010a). Authors applied two-stage Bertrand game involving three container terminals located in Karachi Port in Pakistan. The best payoff was found to be in the case of the grand coalition; however, the real winner is the outsider (the terminal at the second port) which earns a better payoff without joining the coalition. Also, with nondiscriminatory fees, the overall profits of terminals located in Karachi are lower than with discriminatory fees, but users are better off with nondiscriminatory percentage fees. Competition and coalition between terminals at two ports were investigated by (Park and Suh, 2015), where authors applied competition as a Bertrand game and cooperation as terminal alliance on four container terminals located in North Port and two terminals in New port of Busan, Republic of Korea. The goal of the investigation was to find equilibrium price and profit between container terminals that are in a competitive relationship. Terminal cooperation was also investigated by (Pujats et al., 2018) where authors applied the Nash Bargaining Solution (NBS) to evaluate and compare four different cooperation policies, where terminals share available demand and capacity. In addition to volume-based formulation, where demand is measured as the number TEUs, authors also modeled cooperation as vessel-based formulation, where demand is measured as a number of TEUs per vessel and compared both types of formulations. The NBS and maximization of total profits policies

outperformed the maximization of minimum profit among all terminals and maximization of minimum profit increase among all terminals when a combined uniformity of profit share among the cooperating terminals and size are considered. Authors also concluded that the commonly used volume-based formulation (which is unrealistic for tactical/operational cooperation plans) can significantly overestimate total profits while at the same time underestimate the profits of the terminals with the higher volume to capacity ratios.

**Table 1: Summary of port and container terminal cooperation/competition and co-opetition.**

| Study                     | Technique   | Methodology  | Objective  | Results  |
|---------------------------|---|--|--|--|
| (Wang et al., 2012)       | <ol style="list-style-type: none"> <li>1. Cournot competition</li> <li>2. Joint profit maximization</li> </ol>                            | Two ports providing differentiated services choose from two possible strategies: either to compete or to form an alliance. | Investigate the factors and conditions affecting alliance formation for ports serving partially overlapping hinterlands in South China.  | Where institutional and political factors prohibit the usual business practices in alliance formation, such as the merger, cross-shareholding, and transfer payments, alliance formation becomes much less likely. |
| (Ignatius et al., 2018)   | <ol style="list-style-type: none"> <li>1. Cournot competition</li> <li>2. Collusion</li> </ol>  | Ports decide to compete or cooperate by generating larger annual container throughput due to the economies of scale.       | Investigate whether competition or a strategic alliance should be adopted by analyzing three main transshipment ports located in Malaysia and Singapore: Port of Singapore (PSA), Port Klang (PKL), and Port of Tanjung Pelepas (PTP). | A strategic alliance between PSA and PTP generates greater profitability to the current hub and spoke network, while PKL should not commit to any cooperative strategy with either PSA or PTP.                     |
| (Wang and Sun, 2017)      | Hotelling game model  | Port enterprises maximize its profit at the same service level or at different service level.                              | Analyze the competition and cooperation among ports based on geographical location, service level, and shipping distance.  | When the service level of port enterprises is same, a cooperative strategy can significantly improve the level of the port group's profit.   |
| (Zhou, 2015)              | <ol style="list-style-type: none"> <li>1. Hotelling model</li> <li>2. Nash equilibrium</li> </ol>   | Ports decide on setting prices under cooperation and competition conditions.   | Analyze which strategy is better competition or cooperation.   | With the same service levels, location is a critical factor for competitive ports and, with a view to capturing greater market share, ports are motivated to form alliances.                                       |
| (Cui and Notteboom, 2018) | <ol style="list-style-type: none"> <li>1. Cournot Competition</li> <li>2. Bertrand Competition</li> <li>3. Quantity-Price Game</li> </ol> | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>1. Port makes quantity or pricing decisions</li> </ol>       | Examined the effects of public/private Port Authorities (PA) oriented objectives and the level of service differentiation on the   | Under Cournot competition, both PA will be reluctant to cooperate, unless the partial public PA will compensate the private PA for joining the alliance. Under all other types of competitions, a PA               |

|                           |   |   |   |   |
|---------------------------|---|---|---|---|
|                           | 4. Price-Quantity Game  | 2. Ports decide to cooperate or compete   | capacity, service price, profits and welfare among competing or cooperating ports.  | with a highly private-oriented objective will be more motivated to cooperate with the private PA. PA with a highly public-oriented objective will show a much lower willingness to cooperate with a private PA under a similar setting.   |
| (Saeed and Larsen, 2010a) | 1. Bertrand game<br>2. Bertrand-Nash equilibrium  | <u>Two-stage game:</u><br>1. Terminals decide to act as a singleton or as a coalition<br>2. Terminals in coalition play cooperatively, otherwise non-cooperative Nash game                          | Analyze the different combinations of coalitions among the three terminals at Karachi Port based on this type of two-stage game.              | The best payoff for all players is in the case of a “grand coalition”. However, the real winner is the outsider (the terminal at the second port) which earns a better payoff without joining the coalition, and hence will play the role of the “orthogonal free-rider”.                                     |
| (Park and Suh, 2015)      | 1. Bertrand Competition<br>2. Maximize Total Joint Profit<br>3. Nash Equilibrium  | Terminals make pricing decisions under cooperation or competition.  | Find equilibrium price and profit between four container terminals in Busan, the Republic of Korea in a competitive and cooperative relation. | In a situation when one container terminal will increase price all, other terminals will keep the current price, when one terminal reduces the price all other terminals will follow.   |
| (Pujats et al., 2018)     | 1. Nash Bargaining Solution<br>2. Maximize total profits<br>3. Maximin profit cooperation<br>4. Maximin profit increase cooperation | For the volume-based formulation, each terminal decides whether to cooperate by receiving or providing demand. For the vessel-based formulation, each terminal decides on which vessels are served. | Evaluate and compare four different cooperation policies for sharing capacity and compare a volume to vessel-based formulations.              | The Nash Bargaining Solution and maximization of total profits policies outperform the maximization of minimum profit among all terminals and maximization of minimum profit increase among all terminals when a combined uniformity of profit share among the cooperating terminals and size are considered. |

## 2.2 PORT AND CONTAINER TERMINAL COMPETITION

In this subsection, we review the literature on game theory approaches, factors and, conditions affecting only seaport, marine container terminal or both. Effects of service level differentiation in inter- and intra-port competition were analyzed by (van Reeve, 2010) where ports competed for transshipment cargo, further (Kaselimi et al., 2011) studied competition between multi-user terminals and, (Yip et al., 2014) competition with terminal concession awarding. The effects of service level and product differentiation as a sequential game were examined by (Zhuang et al., 2014). Strategic interaction by setting prices between ports in their networks was empirically analyzed by (Nguyen et al., 2015). Port capacity investment decisions when ports compete by setting port charges in one stage game with certain demand was studied by (Anderson et al., 2008), with uncertain demand was studied by (Do et al., 2015) and, with stochastic demand was

studied by (Ishii et al., 2013). Luo et al., 2012 studied port capacity investment as a two-stage game. These studies are summarized in Table 2 **Error! Reference source not found.**. Next, we continue to discuss the port and container terminal competition in more detailed matter.

Effects of service level differentiation in inter- and intra-port competition in which two ports compete for cargo transshipment was examined by (van Reeve, 2010) using Hotelling model and Cournot competition. The model showed that the Landlord Port model is Nash equilibrium and that this organizational form yields the highest profits for the port industry, and the highest prices for its customers. Introduction of intra-port competition into the Landlord model decreases industry profits and prices, which makes the port industry reluctant to open itself to such competition. Intra and inter-port competition between multi-user terminals using two-stage game was examined by (Kaselimi et al., 2011) where authors investigated how the shift toward a fully dedicated terminals impact on. At the first level authors used Cournot competition to model terminal competition, taking consideration of terminal capacity and at the second stage authors used Hotelling model to competition between terminal via prices and throughput. Authors concluded that dedicated terminals will lead less profit to the port authorities and users of multi-user terminals, but multi-user terminals were not negatively affected by the introduction of dedicated terminals. Terminal concession awarding at intra- and inter-port competition was studied by (Yip et al., 2014) using two-stage model, where at the first stage ports make terminal award decisions and at the second stage terminals engage in Cournot competition. Model results suggested that terminal operators prefer to control more terminals in the region, terminal operator service expansion at every port will lead to worse results due to an increase of inter- and intra-port competitions. Port authorities with significant market power prefer to introduce inter- and intra-port competition, rather than allowing one terminal operator to monopolize all terminals. Instead of product differentiation, (Zhuang et al., 2014) investigated differentiated services in the sectors of containerized cargo and dry-bulk cargo by modeled port competition using Stackelberg game and a simultaneous game. Authors suggested the following: that 1) without proper coordination, ports may choose to invest in the same type of infrastructures even if there is insufficient demand for multiple ports; 2) without government intervention, port specialization might be achieved, but at the expense of over-investment and excessive competition; 3) leader ports enjoy substantial first-mover advantages in terms of greater profit and larger traffic volume. Strategic interaction by setting prices between ports in their networks was empirically analyzed by (Nguyen et al., 2015). While considered berth dues and channel authors applied two-stage game on three Australian port networks, in Queensland, South Australia and Victoria, and Western Australia states, where at the first stage ports estimate price response functions, and at the second stage ports identify links in the port network and analyze strategic interactions. Authors concluded while some ports appear to strategically interact with each other in price setting, other ports prefer to set their own prices independently of each other. Moreover, strategic pricing can be asymmetric rather than symmetric.

Port capacity investment decisions between ports of Busan, Korea and, Shanghai, China was examined by (Anderson et al., 2008) using Bertrand competition. Author suggested that investments should not be undertaken throughout the East Asia. Authors also concluded that governments must be mindful of current and planned development by competitors, who have the potential to capture or defend market share. Port capacity expansion was also examined by (Do et al., 2015) where authors modeled competition between Hong Kong and Shenzhen Port and investigated the decision-making process of investment in capacity expansion using uncertain

demand and payoff in a two-person game. Shenzhen was found to be the dominant port in long-term strategy. Strategic port charges in the timing of port capacity investment as inter-port competition between two ports using Cournot competition was examined by (Ishii et al., 2013). Results showed that while the theoretical model explained that ports should set lower rates when demand elasticity is high and port expansion activities are both high and almost simultaneously undertaken by competing ports, the actual decision by the government for the corresponding ports was contrary to the theory. Port capacity investment decisions were also studied by (Luo et al., 2012), where authors applied a two-stage game to study container port competition between the port of Hong Kong and Shenzhen, where at upper-level ports decide on capacity investment and at lower level play Bertrand game. Specifically, authors studied the competitive outcomes when the market demand is increasing, and the two ports have different competitive conditions. Authors concluded that the absence of non-market protective measures when a new port has a stronger competitive power, pricing and capacity expansion measures may not be effective in preventing the growth of the new port. Equilibrium and capacity development condition and should be checked to prevent the new port from growing. The best strategy for the dominating port is to increase the market competitiveness, to reduce the possibility of being overtaken by the new player in the future market competition.

**Table 2: Summary of port and container terminal competition.**

| Study                  | Technique   | Methodology   | Objective  | Results   |
|------------------------|---|---|--|---|
| (van Reeve, 2010)      | <ol style="list-style-type: none"> <li>Hotelling model</li> <li>Cournot competition</li> </ol>  | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>Port authorities decide whether to integrate vertically or to separate vertically</li> <li>All players simultaneously make their final choices</li> </ol> | Analyze competition between different service suppliers in a horizontal product differentiation model in which two ports compete for cargo transshipments. | Landlord Port model is Nash equilibrium. Introduction of intra-port competition into the Landlord model decreases industry profits and prices, which makes the port industry reluctant to open itself to such competition.  |
| (Kaslimi et al., 2011) | <ol style="list-style-type: none"> <li>Cournot competition</li> <li>Hotelling model</li> </ol>  | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>Terminal operators compete for quantities taking consideration of their capacity</li> <li>Terminals compete in both prices and throughput</li> </ol>      | Examine how the shift toward a fully dedicated terminal impact on intra-port and inter-port competition between the remaining multiuser terminals.         | Dedicated terminals will lead lower profits to the associated port authorities. Multi-user terminal operators were not negatively affected by the introduction of dedicated terminals in a port they operate or in competing port. User of multi-user terminals will lead to profit loss. |
| (Yip et al., 2014)     | <ol style="list-style-type: none"> <li>Cournot Competition</li> <li>Nash equilibrium</li> </ol> | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>Port makes terminal award decision</li> <li>Terminals set port charges competing in quantity</li> </ol>   | Examined the effects of competition on the awarding of seaport terminal concessions.   | Terminal operators always prefer to control more terminals on the region. When a port authority has significant market power, it prefers to introduce inter- and intra-port competition.  |



|                         |  |  |   |   |
|-------------------------|--|--|---|---|
| (Zhuang et al., 2014)   | <ol style="list-style-type: none"> <li>Stackelberg game</li> <li>Nash Equilibrium</li> </ol>                                       | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>The leader port decides output volumes for both container and bulk cargo operations</li> <li>The follower port decides output volumes in container and bulk cargo operations</li> </ol> | Investigated the port specialization by modeling port competition, where ports provide differentiated services in the sectors of containerized cargo and dry-bulk cargo.    | A port can specialize in a type of cargo for which there is relatively high demand, where it has established capacity first, or for services which require prohibitively high capacity costs. Also, overcapacity is likely if strategic port decisions are made simultaneously instead of sequentially.                                       |
| (Nguyen et al., 2015)   | <ol style="list-style-type: none"> <li>Price leadership</li> <li>Nash Equilibrium</li> </ol>                                       | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>Ports make pricing decisions to maximize profit</li> <li>Identification of network links between ports in the network and strategic interaction</li> </ol>                              | Examine how a port sets its prices for infrastructure services given those of its competitors. Identification of network relationships and analyses strategic interactions. | Integration between ports could help improve not only operational but also allocative efficiency of the network. While some ports appear to strategically interact with each other in price setting, other ports prefer to set their prices independently of each other. Moreover, strategic pricing can be asymmetric rather than symmetric. |
| (Anderson et al., 2008) | Bertrand game  | Each port makes an investment decision by increasing each ports capacity.  | Examine the defensible returns from investment in additional port capacity at Busan, Korea, and Shanghai, China.  | High levels of investments should not be undertaken, throughout East Asia. Governments must rely primarily on estimates of multiplier effects when considering the benefits of being a hub port. Governments must be mindful of current and planned development by competitors.   |
| (Do et al., 2015)       | <ol style="list-style-type: none"> <li>Two-person game model with uncertain demand and payoff</li> <li>Nash Equilibrium</li> </ol> | Ports decide to invest under consideration that demand is uncertain, or payoff is uncertain.   | Examine competing strategies of Hong Kong and Shenzhen Port by investigating the decision-making process of investment in capacity expansion.                               | Shenzhen is the dominant port in long-term strategy. Hong Kong can only gain profit from investing when Shenzhen also does.   |
| (Ishii et al., 2013)    | <ol style="list-style-type: none"> <li>Two-person game model with stochastic demand</li> <li>Nash Equilibrium</li> </ol>           | Port charges are set simultaneously at the beginning of each period, obtaining the best response functions and the Nash equilibrium  | Examine the effect of inter-port competition in the timing of port capacity investment between two ports by applying a game theoretical approach.                           | Ports should set lower rates when demand elasticity is high and port expansion activities are both high and almost simultaneously undertaken by competing ports.  |

|                    |  |  |   |  |
|--------------------|--|--|---|--|
| (Luo et al., 2012) | <ol style="list-style-type: none"> <li>1. Bertrand competition</li> <li>2. Nash equilibrium</li> </ol> | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>1. Each port decides whether to expand its capacity</li> <li>2. Each port sets a price to maximize its profit</li> </ol> | Identify conditions for a port to increase its profit through capacity expansion, and a condition when preemptive pricing by the dominant player is neither credible nor effective. | Competitors will be more inclined to expand when total market demand or market share is increasing. The new port with smaller capacity, lower investment cost, and higher price sensitivity will be more likely to expand. |
|--------------------|--|--|---|--|

### 2.3 GOVERNMENT, PORT AND CONTAINER TERMINAL COMPETITION AND COOPERATION

In this subsection, we review the literature on game theory approaches, factors and conditions affecting government, port and marine container terminal competition and cooperation. Port regulation under centralized and decentralized mode, when governments make capacity decisions and container terminals make tariff and efficiency level decisions was studied by (Zheng and Negenborn, 2014), when governments make cargo fee decision and terminals makes service quality and service price decisions was studied by (Yu et al., 2016). Effects of port privatization in a port competition setting was investigated by (Czerny et al., 2014). Emission control strategies at port areas when port compete and cooperate were examined by (Cui and Notteboom, 2017). Pricing and investment decisions between ports with hinterland congestion, when governments decide on port and hinterland capacity investment and ports compete via price, was examined by (De Borger et al., 2008), when governments decide on port and hinterland capacity investment and ports compete via quantity, was examined by (Wan and Zhang, 2013). These studies are summarized in Table 3. In the next section, we go in a more detailed review of the government, port and marine container terminal competition and cooperation.

Port regulation modes were examined by (Zheng and Negenborn, 2014) where authors compared the centralization mode and the decentralization mode by modeling Stackelberg game between government, ports and costumers. Specifically, authors investigated the effects of port regulation mode on optimal tariffs, port capacities, and port efficiency levels. Authors showed that the tariff, port efficiency level, port service demand, and social welfare are higher under the decentralization mode, while the impact to port capacity and port operator’s profit with different port regulation modes was uncertain. Port regulation under centralized and decentralized mode was also studied by (Yu et al., 2016), where authors used two-stage Hotelling model to study the effects of terminal centralization on regional port competition, in a situation where port governments make cargo fee decisions and terminal operators make service quality and service price decisions. Study showed that governments prefer competitive terminals and, in a situation, when terminals do not have competitive advantages in their service quality, then terminal centralization results in higher profits when comparing to the competition case.

Port ownership, in particular, port privatization was investigated by (Czerny et al., 2014) where authors used two-stage Hotelling game in a setting with two ports located in different countries, serving their home market but also competing from transshipment traffic from the third region. In the two-stage game at the first stage ports decide simultaneously whether to privatize or

maximize social welfare and second stage when ports set port charges in competing for price. Private ports set higher port charges and a reduction of operational cost implies higher port charges. Authors also concluded that if transshipment market size is large enough, privatizing both ports will achieve Nash equilibrium.

The effect on government-imposed emission tax on vessels and port operations for emission control on two ports: a purely private port and landlord port was investigated by (Cui and Notteboom, 2017) using Cournot, Bertrand competition and cooperation with differentiated service. Authors suggested that stricter environmental protection efforts must be enhanced in the case of port cooperation than in case of inter-port competition. The total emission tax revenue was found to be always higher than the overall environmental damage in the cooperative scenario.

Pricing and investment decisions between competing ports with hinterland congestion were studied by (De Borger et al., 2008). Authors analyzed the interaction between the port pricing and optimal investment policies in port and hinterland capacities by imposing congestion tolls on the hinterland network using two-stage game, where at the upper level governments play Cournot type of game by making decisions with respect to port and hinterland investments and considering the pricing behavior of ports and at the lower level ports play Bertrand game by determining port prices, considering the potential congestion at the port itself and the hinterland transport network. Authors concluded that the investment in port capacity will reduce prices and congestion at each port but increases hinterland congestion in the region where investment was made. Investment in ports hinterland is likely to lead to more port congestion and higher prices for port use, and to less congestion and a lower price at the competing port. Imposing congestion tolls on the hinterland road network raises both port and hinterland capacity investments. Hinterland congestion and seaport competition was further studied by (Wan and Zhang, 2013), similarly to (De Borger et al., 2008) authors investigated a two-stage game in which local governments decide on the port and hinterland capacities by imposing congestion tolls on the hinterland network, but unlike (De Borger et al., 2008) authors studied road tolls more detailed manner by looking at both fixed-ratio and the discriminative tolls. Also, instead of assuming price competition between ports, authors used quantity competition. Author results suggested that the increase in road capacity or increasing tolls may increase ports profit and reduce the rival ports profit by tolling above the marginal external congestion costs. When the discriminative toll system is implemented, commuters are tolled at the marginal costs, while truck tolls are much lower. High tolls by a region relieve its road congestion, but it may increase road congestion in the rival region.

**Table 3: Summary of government, port and container terminal competition/cooperation.**

| Study                       | Technique   | Methodology   | Objective   | Results   |
|-----------------------------|---|---|---|---|
| (Zheng and Negenborn, 2014) | Stackelberg game  | <p><u>Three-stage game:</u></p> <ol style="list-style-type: none"> <li>1. Government decides on the capacities of the public and the private terminals</li> <li>2. Government and the private terminal operator play a simultaneous duopoly game</li> <li>3. Consumers make choices between the public and private terminals</li> </ol> | Analyze optimal tariffs, capacities and efficiency levels under the centralization mode and the decentralization mode.  | Tariff under centralization mode is higher. Comparisons of port capacity and port operator's profit under centralization mode and decentralization mode are uncertain. Port efficiency level, demand and social welfare under centralization mode is lower. |
| (Yu et al., 2016)           | <ol style="list-style-type: none"> <li>1. Hotelling model</li> <li>2. Nash equilibrium</li> </ol> | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>1. Port governments make cargo fee decision</li> <li>2. Terminal operators make service quality and service price decisions.</li> </ol>  | Examined interactions between governments and port operators, by studying dual gateway-port system where two port governments compete on cargo fees and two terminals compete on service price and service quality under a decentralized model and centralized model. | Governments prefer terminals to compete under the decentralized model. When the terminals do not have advantages in their service quality, terminal centralization should be encouraged by terminal operators.  |
| (Czerny et al., 2014)       | Hotelling model   | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>1. The governments in both countries simultaneously decide on the mode of port operation (privatization, or no privatization)</li> <li>2. Ports choose prices (port charges)</li> </ol>  | Investigate the effect of port privatization in a setting with two ports located in different countries, serving their home market but also competing for transshipment traffic from a third region.  | If the transshipment market is sufficiently large, both ports are privatized in equilibrium and that the national welfare of the port countries increases compared to a situation where the ports are kept under public operation.                          |

|                           |  |  |  |  |
|---------------------------|--|--|--|--|
| (Cui and Notteboom, 2017) | <ol style="list-style-type: none"> <li>1. Cournot competition</li> <li>2. Bertrand competition</li> <li>3. Nash equilibrium</li> </ol> | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>1. Government decides on the level of emission control tax and how much to privatize port</li> <li>2. Ports decide on the abatement level and quantity/price simultaneously in Cournot/Bertrand competition or cooperation settings</li> </ol> | Analyze the situation in which the government imposes a certain emission tax on vessels and port operations for emission control in port areas.  | Government will prefer a highly public port in the cooperation scenario. Stricter environmental protection must be imposed under cooperation. The total emission tax revenue is always higher than the overall environmental damage under cooperation.   |
| (De Borger et al., 2008)  | <ol style="list-style-type: none"> <li>1. Cournot type competition</li> <li>2. Bertrand competition</li> </ol>                         | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>1. Governments decide on port capacity, hinterland capacity and road tolls</li> <li>2. Ports set port charges engaging in price competition</li> </ol>   | Studied pricing and investment decisions in market where congestible facilities compete for traffic, and where this traffic shares a congestible downstream facility with other users. | Investment in port capacity reduces prices and congestion at each port but increases hinterland congestion in the region where investment was made. Investment in ports hinterland is likely to lead to more port congestion and higher prices for port use, and less congestion and a lower price at the competing port. Imposing congestion tolls on the hinterland road network raises both port and hinterland capacity investments. |
| (Wan and Zhang, 2013)     | <ol style="list-style-type: none"> <li>1. Cournot competition</li> <li>2. Cournot equilibrium</li> </ol>                               | <u>Two-stage game:</u> <ol style="list-style-type: none"> <li>1. Governments decide on hinterland capacity and road tolls</li> <li>2. Ports set port charges competing in quantity</li> </ol>  | Examined interaction between urban road congestion and port competition as part of the rivalry between alternative intermodal chains.  | Increase in road capacity or increasing tolls by a chain may increase its port's profit and reduce the rival port's profit. When a discriminative toll system is implemented, commuters are tolled at the marginal external congestion costs while truck tolls are much lower.   |

## 2.4 GOVERNMENT, PORT AND SHIPPER'S COMPETITION

Strategic investment decisions of local governments on inland transportation infrastructure in the context of competition between two seaports, which have respective catchment areas and common hinterland was investigated by (Basso et al., 2013). Authors used three-stage Hotelling model, where at the first stage governments decide investment in packability and at the second stage ports decide on prices on prices, and lastly, shippers decide whether they will demand the product or not and which port to use. Authors main finding included that increasing investment in the hinterland lowers charges at both ports, but the increasing investment in a port's catchment area will cause a severer reduction in charge at its port than at the rival port. This study is summarized in Table 5.

## 2.5 GOVERNMENT, PORT AND MANUFACTURING FIRM COMPETITION

The effects of port privatizations on port usage fees, firm profits, and welfare in context of port and manufacturing firm competition located in two countries, home and foreign, was investigated by (Matsushima and Takauchi, 2014) using three-stage game, where at the upper level governments decide whether to privatize port its port or not, at second stage ports independently set their port usage fees and finally firms simultaneously compete in quantity in both countries. Authors showed that, when the per unit transport cost is sufficiently low, both ports are privatized, or no port is privatized, when the per unit transport cost is moderate, both ports are privatized, when the per unit transport cost is high enough, none of the ports are privatized; despite this, privatization would lower port usage fees. This study is summarized in Table 5**Error! Reference source not found.**

## 2.6 PORT AND LINER SHIPPING COMPETITION AND COOPERATION

In this subsection, we review the literature on game theory approaches, factors and conditions affecting port and liner shipping competition and cooperation. Horizontal and vertical interactions between liners and ports was examined by (Song et al., 2016). Container port competition and collusion for transshipment cargo in presence of shipping lines were investigated by (Bae et al., 2013). Horizontal and vertical interaction between hub ports and liner shippers using game theoretic network design model was examined by (Asgari et al., 2013), between hub-spoke ports and liner shippers was examined by (Tuljak-Suban, 2017). Service network design for shipping lines or alliances, when shipping lines operate in a set of ports was examined by (Angeloudis et al., 2016). These studies are summarized in Table 4**Error! Reference source not found.** In the next section we provide an in-depth review of port and liner shipping competition and cooperation.

Horizontal and vertical interaction between liners and ports where investigated by (Song et al., 2016) in a two-stage game using Bertrand competition and Multinomial Logit model, where at the first stage shipping lines make port of call decisions, and at the second stage, each port makes port pricing decision to maximize their profit. Authors found that when ports and liners are treated as identical players the Nash Equilibrium result to the lowest possible service charge. When ports and liners are treated as different players, liners respond to the game not by raising its service charge, but grasping container volume, ports, on the other hand, have more freedom to set a relatively high level of service charge than the liners. Cooperating rather than competing with regional ports can be a good strategy, especially since port capacity can be constrained by geography, neighboring ports can serve as overflow nodes. Container port competition and collusion for transshipment cargo in presence of shipping lines was investigated by (Bae et al., 2013), where authors user two-stage game, where at first stage ports engage in Bertrand coemption or collusion by making pricing decisions, and at the second stage by observing ports capacities, prices and transshipment levels shipping lines engage in Cournot competition by making port of call decisions. Authors concluded that shipping lines prefer the port that provides a higher transshipment level, only if its capacity is sufficient to eliminate the accompanying

congestion effect. Port that possesses excessive capacity can cut the price to invite more demand as its spare capacity can balance the congestion effect. When both ports are congested, a high transshipment port lowers the price to retain its demand as its transshipment level results in high congestion cost to shipping lines. The port collusion model yields a higher port price than that of the non-cooperative model, and the profit margin of the social optimum model is higher than that of the non-cooperative model.

Competition and cooperation strategies between ports and shipping companies using game theoretic network design model were investigated by (Asgari et al., 2013), by developing Stackelberg game, where the leader of the game shipping companies decide on the route network design and followers the hub ports decide on their total handling costs. Three scenarios were considered: (i) perfect competition between the hub ports, (ii) perfect cooperation between the hub port, and (iii) cooperation between the shipping companies and the hub ports. Authors found that in short-term, dynamic pricing is the easiest way to manage pricing. Alternatively, change of handling charges can maximize its capacity and competition power. In the medium term, alliance with leading shipping companies can help partially guarantee market share. In the long run, strategic alliances can be a good strategy, especially since geography and neighboring ports can constrain port capacity. Competition and cooperation in a hub and spoke shipping network was examined by (Tuljak-Suban, 2017), where author investigated the relationship between ports container terminal incomes and the incurred costs of the shipping operators in the North Adriatic hub and spoke system with respect to the leadership position of the ship owners. Author used two-stage Stackelberg game, where at the upper level shipping companies act as leaders and solve the Vehicle Routing Problem with Pickup and Delivery (VRPPD) by taking into count the navigation and handling costs to make port of call decision, and at the lower level the spoke ports decide on handling charges under port cooperation, competition or cooperation between spoke ports and shipping companies. Author concluded that there is no optimal strategy between ship companies and spoke ports, in the case of port competition could lead to a reduction in the activities of the weaker port, in the case of port cooperation between spoke ports could raise incomes and improve container transshipment services. Service network design, container assignment and service provision of shipping lines or alliances, when shipping lines operate in a set of ports as a monopolist or engage in duopoly was analyzed by (Angeloudis et al., 2016) using three-stage game, where at the first stage shipping lines or alliances decide on investment in their fleet, in the second stage, shipping lines or alliances individually design their services and solve the route assignment problem with respect to the transport demand they expect to serve, and finally shipping lines or alliances compete in terms of freight rates on each origin–destination movement. Authors showed that the monopoly shipping line or alliance does not cover all possible market demand, because of the high cost of available services mainly linked to transshipment. Also, the monopoly never satisfies all the existing demand in ports that are served through the chosen network. When a duopoly was considered shipping lines or alliances tend to choose different service networks to limit the competitive pressure.

**Table 4: Summary of port and liner shipping competition and cooperation.**

| Study                 | Technique   | Methodology  | Objective   | Results   |
|-----------------------|---|--|---|---|
| (Song et al., 2016)   | <ol style="list-style-type: none"> <li>Bertrand competition</li> <li>Multinomial Logit model</li> </ol>           | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>Each shipping line makes port call decision</li> <li>Each port makes port pricing decisions to maximize its profit</li> </ol>   | Examine horizontal and vertical interactions among liners and ports.  | When ports and liners are treated as identical players, Nash equilibrium prices result to the lowest possible service charge. When ports and liners are treated as different players, liners respond to the game not by raising its service charge but grasping container volume. Ports have more freedom to set a relatively high level of service charge than the liners.   |
| (Bae et al., 2013)    | <ol style="list-style-type: none"> <li>Bertrand competition and collusion</li> <li>Cournot competition</li> </ol> | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>Each port makes port pricing decisions to maximize its profit</li> <li>Each shipping line makes port call decision</li> </ol>   | Examine how different levels of port capacities, prices and transshipment levels affect the ports congestion levels, and how a port can capture a greater transshipment demand with appropriate port pricing and capacity building. | Shipping lines tend to assign more port calls to the port that offers a lower price and a larger capacity. Shipping lines prefer the port that provides a higher transshipment level, only if its capacity is sufficient to eliminate the accompanying congestion effect. The port collusion model yields a higher port price and the profit margin of the social optimum model than that of the non-cooperative model. |
| (Asgari et al., 2013) | <ol style="list-style-type: none"> <li>Stackelberg game</li> <li>Nash equilibrium</li> </ol>                      | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>Shipping companies decide on the route network design</li> <li>Hub ports decide on total handling costs</li> </ol>  | Investigate the competition and cooperation strategies amongst three parties: two major container hub ports and the shipping companies.   | In the short term, dynamic pricing is the easiest way to manage pricing. In the medium term, forming strategic alliances with leading shipping companies can help partially guarantee market share. In the longer run, strategic alliances with rival ports can guarantee market share and profit.  |
| (Tuljak-Suban, 2017)  | <ol style="list-style-type: none"> <li>Stackelberg game</li> <li>Nash Equilibrium</li> </ol>                      | <p><u>Two-stage game:</u></p> <ol style="list-style-type: none"> <li>The leader shipping operators make port call decision</li> <li>The follower spoke ports decide on handling charges under cooperation/competition between ports or cooperation between spoke ports and shipping operators</li> </ol> | Examine competition or cooperation of the container terminals in the North Adriatic hub and spoke system with respect to the leadership position of the ship owners.  | There is no optimal strategy in the case of cooperation between ship companies and spoke ports. Competition between ports could lead to a reduction in the activities of the weaker port. Cooperation between spoke ports could raise incomes and improve container transshipment services.   |



|                           |  |   |  |   |
|---------------------------|--|---|--|---|
| (Angeloudis et al., 2016) | <ol style="list-style-type: none"> <li>1. Bertrand competition</li> <li>2. Nash equilibrium</li> </ol> | <u>Three-stage game:</u> <ol style="list-style-type: none"> <li>1. Firms simultaneously invest in their fleet</li> <li>2. They individually design their services and solve the route assignment problem</li> <li>3. Firms compete in terms of freight rates on each origin–destination movement</li> </ol> | Determine an optimal set of liner services, given the presence of a competing shipping firm. | The monopoly firm does not cover all possible market demand. The monopoly never satisfies all the existing demand in ports that are served through the chosen network, when a duopoly is considered, the scope for demand satisfaction improves, the existing market demand is not fully satisfied. |
|---------------------------|--|---|--|---|

## 2.7 OCEAN CARRIER, PORT TERMINAL AND LAND CARRIER COMPETITION

Pricing and routing decisions between ocean carriers, land carriers and terminal operators in maritime freight transportation network were investigated by (Lee et al., 2012). Authors used non-cooperative hierarchical game model, where at the first level carriers determine service charges and delivery routes and the second level terminal operators decide on port throughput and service cost, and finally, land carriers decide on service demand and land transportation costs. Authors noted that the developed model can be a useful tool to examine and understand the dynamics and decision-making processes of various stakeholders involved in the oligopolistic freight shipping market. This study is summarized in Table 5.

**Table 5: Summary of other type of maritime transportation cooperation/competition.**

| Study                | Technique       | Methodology   | Objective  | Results  |
|----------------------|-----------------|---|--|--|
| (Basso et al., 2013) | Hotelling model | <u>Three-stage game:</u> <ol style="list-style-type: none"> <li>1. Governments decide investment in accessibility</li> <li>2. Ports decide on prices to maximize a weighted average of profits and consumer surplus</li> <li>3. Shippers decide whether they will demand the product or not, and which port to use</li> </ol> | Investigate the strategic investment decisions of local governments on inland transportation infrastructure in the context of seaport competition. | Investment in the common hinterland lowers charges of both ports. Investment in the captive catchment area of a certain port will cause severer reduction in its port charge than that of the rival port. Investment in the port region will reduce the welfare of the rival port region but improve the welfare of the common inland region. Investment in the inland region will harm the port region with poorer accessibility. |

|  |   |  |  |  |
|--|---|--|--|--|
| <p>(Matsushima and Takauchi, 2014)</p> | <ol style="list-style-type: none"> <li>1. Bertrand competition</li> <li>2. Cournot competition</li> </ol>                               | <p><u>Three-stage game:</u></p> <ol style="list-style-type: none"> <li>1. Each government decides whether to privatize its port or not</li> <li>2. Ports set their port usage fees</li> <li>3. The two firms simultaneously compete in terms of quantity</li> </ol>  | <p>Investigate how port privatization affects port usage fees, firm profits, and welfare in the context of port and manufacturing firm competition located in two countries.</p> | <p>When the unit transport cost is high, port privatization reduces port usage fees, although neither government has an incentive to privatize its port. The government of the smaller country, in terms of market size, is more likely to privatize its port, and the government of the larger country is more likely to nationalize its port to protect its domestic market.</p> |
| <p>(Lee et al., 2012)</p>              | <ol style="list-style-type: none"> <li>1. Non-cooperative game model with oligopolistic players</li> <li>2. Nash Equilibrium</li> </ol> | <p><u>Three-stage game:</u></p> <ol style="list-style-type: none"> <li>1. Ocean carriers determine the profit based on service demand and transportation cost functions</li> <li>2. Port Terminals determine the profit from the port throughput and service cost functions</li> <li>3. Oligopolistic Land carriers determine the profit based on land carrier service demand and land transportation functions</li> </ol> | <p>Investigate interactions among oligopolistic ocean carriers, land carriers and port terminal operators in maritime freight transportation networks.</p>                       | <p>Provided a useful tool to examine and understand the dynamics and decision-making processes of various stakeholders involved in the oligopolistic freight shipping market.</p>  |

### 3.0 CONCEPTUAL AND MATHEMATICAL FRAMEWORK AND COMPLEXITY ANALYSIS

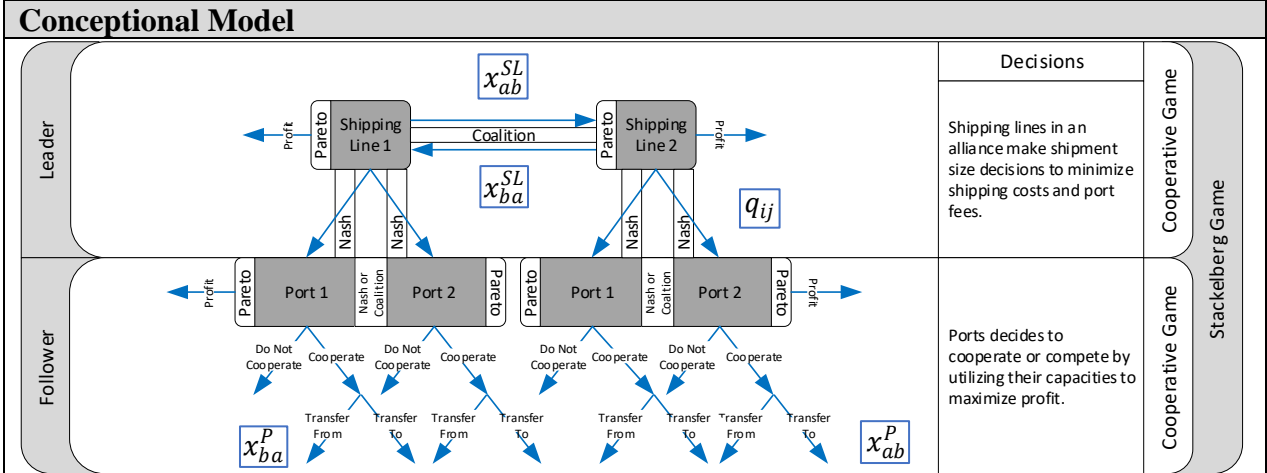
In this section, we propose a conceptual (Figure 1 **Error! Reference source not found.**) and mathematical framework for port, terminal operators, and liner shipping companies cooperation/competition using the Stackelberg model, where the shipping lines in alliance act as leaders by minimizing shipping costs and terminal fees, and the container terminals act as followers by making decision to compete or engage in cooperation with the other terminal by utilizing each other's capacities with objective to maximize profit. The proposed framework is an extension of a model proposed by (Pujats et al., 2018), where four different cooperation policies and two different demand assumptions were evaluated and compared.

The game theoretic model developed in this research, to analyze a competition between two shipping lines in an alliance and two marine container terminal operators (MCTOs) that have already engaged in a cooperative agreement and are in two different ports makes several assumptions. First, we assume that the MCTOs can negotiate and share the available (seaside and landside) resources/capacity to maximize profits. Second, we assume that the shipping lines of the alliance can utilize each other's capacity, due to already negotiated Vessel Sharing Agreement(s), where each shipping line shares vessel capacity, proportional to total shipping line capacity with objective to minimize shipping costs and terminal fees. Third, the model only considers shipping lines of a single alliance and assumes that both shipping lines depart from a single port, thus excluding any costs associated with container transfer between shipping lines. We model competition between the alliance shipping lines and MCTOs as a Stackelberg leadership game, where, the leader of the game, the shipping lines, makes decisions first and the follower the MCTOs responds. At the first stage of the game, the alliance is simultaneously minimizing shipping costs and terminal fees, where the shipping costs ( $sc_{ij}(q_{ij})$ ) (per TEU) are given as a function of number of containers shipped ( $q_{ij}$ ) by shipping line ( $i$ ) to port ( $j$ ) and terminal fees ( $hf_{ij}(V_{ij}^a)$ ) are given as function of volume of containers handled at terminal  $j$  after shipping lines  $i$  shipment. Shipping line alliance is minimizing the shipping costs and terminal fees by utilizing shipping line capacity through a container volume transfer ( $x_{ab}^{SL}$ ) between shipping lines and deciding on the volume of containers ( $q_{ij}$ ) shipped by shipping line ( $i$ ) to port ( $j$ ). At the second stage, see Figure 1 **Error! Reference source not found.**, of the game MCTOs decide to engage in a cooperative or non-cooperative game. MCTOs under cooperation maximize their profits by utilizing their capacities through container volume transfer  $x_{ab}^P$  between container terminals.

The model is constructed as a non-cooperative game between the shipping lines and the container terminals, where at each level a cooperative game is played. The optimal outcome of a non-cooperative game between the shipping lines and container terminals can be determined using Nash-equilibrium, which describes a set of strategies between the players, such that no player can gain more by changing his or her strategies. Furthermore, as the model is constructed as a sequential game, it involves multi-stage decisions, thus the Nash-equilibrium is determined using backwards inductions starting by first determining the equilibrium for the last sub-game. Our model also includes two cooperative subgames, where at the upper-level, liner shipping alliance seek to achieve Pareto-efficiency a state where the containers are distributed among the

shipping lines in the most efficient way, so that no shipping line can be put in better position, without worsening the position of other shipping lines. Similarly, at the lower level, if container terminals engage in cooperation then Pareto-efficiency should be achieved; otherwise, containers terminals play a non-cooperative game, and the optimal outcome is determined using Nash-equilibrium. Also, when cooperative games are considered, the stability of coalition and fairness of payoff distribution among players should be considered. Next, we present the conceptual and mathematical framework.

## TWO STAGE STACKELBERG GAME WHERE THE SHIPPING LINES ACT AS LEADERS AND THE CONTAINER TERMINALS ARE THE FOLLOWERS



**Figure 1: Conceptual Model for Two Stage Stackelberg Game**

### Notation

- $i \in I$  – set of shipping lines,  $i \in (1, 2)$
- $j \in J$  – set of container ports,  $j \in (1, 2)$

### Parameters for the Shipping Line, Alliance Model

- $Q_i^{SL}$  – shipping lines  $i$  demand
- $Q_{ij}^{SL}$  – shipping lines  $i$  demand to port  $j$
- $C_{ij}^{SL}$  – shipping lines  $i$  available capacity to port  $j$  (Vessel Sharing Agreement)
- $Q_j$  – alliances demand to port  $j$
- $sc_{ij}$  – shipping lines  $i$  shipping cost to port  $j$  per container
- $c_{ij}$  – shipping lines  $i$  shipping cost shipping containers to port  $j$
- $q_{ij}^c$  – volume of containers shipped by shipping line  $i$  to terminal  $j$  under cooperation
- $r_a^{SL} = 1$  – if containers are transferred to shipping line  $a \in I$
- $w_a^{SL} = 1$  – If containers are transferred from shipping line  $a \in I$

### Decision Variables for the Shipping Line, Alliance Model

- $q_{ij}$  – container volume demand by shipping line  $i$  to port  $j$
- $x_{ab}^{SL}$  – volume of containers transferred from shipping line  $a \in I$  to shipping line  $b \in I$  under cooperation

### Parameters for the Port, Terminal Model

- $C_j^P$  – ports  $j$  capacity

|  |
|--|
| <p> <math>hc_{ij}</math> – ports <math>j</math> handling cost of handling one unit of container shipped by shipping line <math>i</math><br/> <math>hf_{ij}</math> – ports <math>j</math> handling fee of handling one unit of container shipped by shipping line <math>i</math><br/> <math>V_j^b</math> – volume of containers handled at terminal <math>j</math> before shipping lines <math>i</math> shipment<br/> <math>V_{ij}^a</math> – volume of containers handled at terminal <math>j</math> after shipping lines <math>i</math> shipment<br/> <math>V_j</math> – volume of containers handled at terminal <math>j</math><br/> <math>pf_a^c</math> – handling fee per container for demand diverted to terminal <math>a \in J</math><br/> <math>r_a^P = 1</math> – if containers are transferred to terminal <math>a \in J</math><br/> <math>w_a^P = 1</math> – If containers are transferred from terminal <math>a \in J</math><br/> <math>prl_a</math> – terminal <math>a \in J</math> profit loss from handling fees of diverted demand from any other terminals<br/> <math>p</math> – the percentage of the origin terminal handling fee charged at the destination terminal (for diverted demand diverted) </p> |
| <b>Decision Variables for the Port, Terminal Model</b>   |
| <p> <math>x_{ab}^P</math> – volume of containers (TEUs) transferred from terminal <math>a \in J</math> to terminal <math>b \in J</math> under cooperation, where <math>a \neq b \in J</math> </p>  |
| <b>Functions</b>   |
| <p> <u>Terminal handling cost function per TEU (cost endured by the terminal operator) – (see Pujats et al., 2018)</u> </p> $hc_{ij}(V_{ij}^a) = \left[ \alpha_1 \left( \frac{V_{ij}^a}{C_j^P} \right)^2 - \alpha_2 \left( \frac{V_{ij}^a}{C_j^P} \right) + pc_j \right]$ <p>where <math>pc_j</math> is the base container handling cost for terminal <math>j \in J</math> without cooperation</p> <p> <u>Terminal handling fees function per TEU (user cost) – (see Saeed and Larsen 2010)</u> </p> $hf_{ij}(V_{ij}^a) = \left[ \beta_1 \left( \frac{V_{ij}^a}{C_j^P} \right)^2 - \beta_2 \left( \frac{V_{ij}^a}{C_j^P} \right) + pf_j \right]$ <p>where <math>pf_j</math> is the base container handling fee charged by terminal <math>j \in J</math></p> <p> <u>Shipping cost function per TEU (cost endured by shipping lines)</u> </p> $sc_{ij}(q_{ij}) = \frac{c_{ij}}{q_{ij}}$  |
| <b>STAGE I</b>   |
| Shipping lines in an alliance and cooperate by making shipment size decisions.   |
| <b>Objective Functions - Shipping Lines and Shipping Line Alliance</b>   |
| <p> <u>Shipping lines objective function</u> </p> $\min \pi_i = \sum_{j \in J} \left( sc_{ij}(q_{ij}) + hf_{ij}(V_{ij}^a) \right) q_{ij}, \forall i \in I$ <p> <u>Shipping lines objective function under cooperation</u> </p> $\min \pi_i = \sum_{j \in J} \left( sc_{ij}(q_{ij}^c) + hf_{ij}(V_{ij}^a) \right) q_{ij}^c, \forall i \in I$ <p> <u>Shipping line alliance objective function</u> </p>  |

$$\min \pi = \sum_{i \in I} \sum_{j \in J} (sc_{ij}(q_{ij}^c) + hf_{ij}(V_{ij}^a)) q_{ij}^c$$

**s.t.**

Container volume shipped should satisfy the demand

$$Q_j = \sum_{j \in J} q_{ij} \quad \forall i \in I$$

Container volume shipped to port j by shipping line i should not exceed shipping lines i available capacity to port j

$$\sum_{j \in J} q_{ij} \leq C_{ij}^{SL}$$

Container volume shipped by shipping line a ∈ I under cooperation

$$q_{ij}^c = q_{ij} + \sum_{b \in I} x_{ba}^{SL} - \sum_{a \in I} x_{ab}^{SL}, \forall a \in I$$

Shipping lines either receive or provide demand (but not both)

$$r_a^{SL} + w_a^{SL} \leq 1, \forall a \in I$$

Volume (TEUs) transferred from shipping line a ∈ I to a shipping line b ∈ I has to be less than or equal to the demand at shipping line a ∈ I under no cooperation

$$\sum_{b \in J} x_{ab}^{SL} \leq w_a^{SL}(q_{aj}), \forall a \in I$$

Containers transferred to shipping line a ∈ I cannot exceed the available demand at all the other shipping lines

$$\sum_{b \in I} x_{ba}^{SL} \leq r_a^{SL} \left( \sum_{b \neq a \in I} q_{bj} - q_{aj} \right), \forall a \in I$$

Joint profit of alliance under cooperation scenario will be greater or equal to its profits under the no cooperation scenario

$$\sum_{i \in I} \pi_i(q_{ij}^c) - \pi_i(q_{ij}) \geq 0$$

**STAGE II** (Pujats et al., 2018)

Ports decide to cooperate or compete by utilizing each other's capacities.

**Objective Functions - Ports and Port Cooperation**

Terminal Profit Function under competition

$$\max \pi_j = \sum_{i \in I} (hf_{ij}(V_{ij}^a) - hc_{ij}(V_{ij}^a)) q_{ij}, \forall j \in J$$

Terminal a ∈ I Profit Function under cooperation

$$\max \pi_j^c = \sum_{b \neq a \in I} hf_{ij}(V_{ia}^a)(V_{ia}^a) - \sum_b x_{ba}^P p f_b^c - \sum_b x_{ab}^P h f_a - hc_{ij}(V_a^c) V_a^c, \forall j \in J$$

*s.t.*

Volume of containers handled at terminal j after shipping lines i shipment

$$V_{ij}^a = V_j^b + q_{ij}$$

Volume of containers handled at terminal j

$$V_j = \sum_{i \in I} V_{ij}^a, \forall j \in J$$

A terminal can either receive or provide demand (but not both)

$$r_a^p + w_a^p \leq 1, \forall a \in J$$

Demand at any terminal cannot exceed capacity (this constraint is not necessary and can be dropped in cases of monotonically increasing profit function for any of the terminals)

$$V_a^c \leq C_a^p, \forall a \in J$$

Profit for any terminal under any cooperation scenario will be greater or equal to its profits under the no cooperation scenario

$$\pi_i(V_a^c) - \pi_i(V_{ia}^a) \geq 0, \forall a \in J$$

Volume (TEUs) transferred from terminal a ∈ J to a terminal b ∈ J has to be less than or equal to the demand at terminal a ∈ I under no cooperation

$$\sum_{b \in J} x_{ab}^p \leq w_a^p(V_{ia}^a), \forall a \in J$$

Volume handled at terminal a ∈ I under cooperation

$$V_a^c = V_{ia}^a + \sum_{b \in J} x_{ba}^p - \sum_{a \in J} x_{ab}^p, \forall a \in J$$

Containers transferred to terminal a ∈ I cannot exceed the available demand at all the other terminals

$$\sum_{b \in I} x_{ba}^p \leq r_a^p \left( \sum_{b \neq a \in J} V_b - V_{ia}^a \right), \forall a \in J$$

Handling fee of transferred demand is (100-p)% of the handling fees at the origin terminal (under no cooperation).

$$pf_a^c \leq p * hf_b(V_{ia}^a) \forall a \in J, p \leq 1$$

Estimation of profit increase (handling fees portion) for demand diverted to terminal a ∈ J

$$prg_a = \sum_{b \in J} x_{ab}^p pf_{ab}^c, \forall a \in J$$

Estimation of profit loss (handling fees portion) for demand diverted from terminal a ∈ J

$$prl_a = \sum_b x_{ba}^p hf_a \forall a \in J$$

Total volume handled before is equal to total volume handled after

$$\sum_{a \in J} V_a^c = \sum_{a \in J} V_{ia}^a$$

### Model Complexity

Our model complexity arises from the point that it has been constructed as a bilevel optimization problem in which a sequential game is played between shipping lines and ports. At the first level, the leader, shipping lines, make strategic decisions to optimize their objective functions, then given shipping line strategies the follower, ports, makes decisions to optimize objective functions. Model complexity further has been increased at both stages of the model, where at the first stage shipping lines have formed an alliance and play a cooperative game to minimize cost and at the second stage ports must decide to play a cooperative or non-cooperative game with the objective to maximize profits. In our model, we can find both the non-cooperative and cooperative equilibriums. We can find the cooperative equilibrium between shipping lines in the alliance and between ports if ports decide to cooperate. A non-cooperative equilibrium in our model can be reached between shipping lines and ports and in a scenario where ports decide to compete. Due to the complexity of the bilevel problem, a heuristic method could help overcome the many challenges of bilevel problem.

## 3.1 CASE STUDY: PORT COOPERATION UNDER FIXED DEMAND

In this subsection we present an application of a subcase of the full model proposed in the previous subsection to demonstrate the versatility and implications of the proposed framework. In this subcase, we assume that marine container terminal operators (MCTOs) can negotiate and share the available (seaside and landside) resources/capacity to maximize profits. MCTOs cooperation, in the sense of resource sharing, optimizes capacity utilization without capital investment which in turn can lead to higher profitability, sustainability, and resilience to market fluctuations). In this study, we assume that MCTOs have already formed a strategic alliance that allows them to share their resources. The objective of the subsection is to evaluate and compare four different cooperation policies (i.e., objective functions) for sharing capacity (i.e., the allocation of demand to terminals) and compare a volume (demand is measured in TEUs) to vessel (demand is measured in vessels) based formulations. The former formulation can be viewed as a planning tool, while the latter as a tactical/operational tool.

Let  $I = \{1, \dots, i\}$  be the set of terminals,  $C_i, i \in I$  the capacity of terminal  $i \in I$ , and  $V_i, i \in I$  the volume of containers handled at terminal  $i \in I$  without cooperation. We define the handling fees, handling costs, and total profit functions as follows:

*Terminal handling cost function (cost endured by the terminal operator)*

$$hc_i(V_i) = \left[ \alpha_1 \left( \frac{V_i}{C_i} \right)^2 - \alpha_2 \left( \frac{V_i}{C_i} \right) + pc_i \right]$$

where  $pc_i$  is the base container handling cost for terminal  $i \in I$  without cooperation.

*Terminal handling fees function (user cost) – (see Saeed and Larsen (Saeed and Larsen, 2010b))*



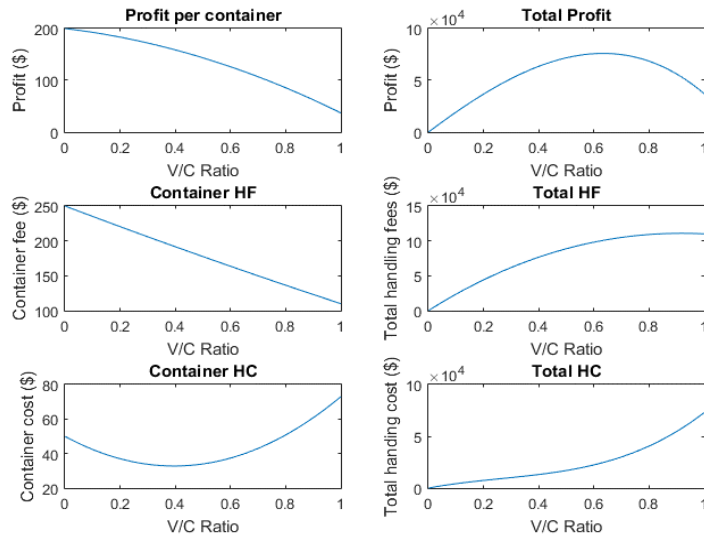
$$hf_i(V_i) = \left[ \beta_1 \left( \frac{V_i}{C_i} \right)^2 - \beta_2 \left( \frac{V_i}{C_i} \right) + pf_i \right]$$

where  $pf_i$  is the base container handling fee charged by terminal  $i \in I$ .

### Terminal Profit Function

$$\pi_i(V_i) = (hf_i(V_i) - hc_i(V_i))V_i$$

Figure 2 shows an example of the terminal profit, handling fees, and handling cost functions by container (left side) and total (right side). Based on (Haralambides, 2002) the maximum profit for the terminal is achieved at V/C ratios in the vicinity of 60% to 80% (although these can be higher or lower depending on the technology and equipment used by terminal). Haralambides, 2002 states that “once a port reaches 70% capacity utilization, congestion ensues in terms of unacceptable waiting times”. Reduction in profits, once V/C ratios exceed this limit, can be attributed to many factors with the main one being reduction in productivity from berth and yard congestion. In this study, we investigate if cooperation between terminals in terms of shared capacity can be beneficial in increasing profits without the need of capital investment to secure “excess capacity”. We propose two approaches for cooperation: one based on volume assignment (which can be used for planning purposes) and one based on vessel assignment (that can be used for tactical/operational purposes). The volume based formulation is more flexible and provides an upper bound to the objective function value of each policy for the vessel based formulation as its relaxation (integrality constraint of demand). In this study, we further assume that handling fees for any diverted demand will not exceed the handling chargers at the origin terminal (i.e., terminal demand is diverted from). In simple terms, any demand that is diverted from one terminal (from now on referred to as origin terminal) to another (from now on referred to as destination terminal) cannot be penalized by higher handling fees than agreed upon with the origin terminal operator. Next, we present the mathematical formulations of both cooperation approaches.



**Figure 2: Example profit, handling cost and handling fee functions plots.**

### 3.2 VOLUME BASED FORMULATION (VOBF)

Let  $x_{ab}, a \neq b \in I$  be the volume (TEUs) transferred from terminal  $a \in I$  to terminal  $b \in I$  under cooperation,  $pf_a^c, a \in I$  handling fee per container for demand diverted to terminal  $a \in I, r_a = 1, a \in I$  if containers are transferred to terminal  $a \in I, w_a = 1, a \in I$  if containers are transferred from terminal  $a \in I, prg_a, a \in I$  profit increase of terminal  $a \in I$  from handling fees of diverted demand from any other terminals,  $prl_a, a \in I$  profit loss from handling fees of diverted demand from terminal  $a \in I$  to any of the other terminals, and  $p$  the percentage of the origin terminal handling fee charged at the destination terminal (for diverted demand diverted). In this study (as discussed in the previous section) we consider and compare four different objective functions: i) NBS, ii) Maximization of total profits, iii) Maximization of minimum profit among all terminals that cooperate, and iv) Maximization of minimum profit increase among all terminals that cooperate.

#### Objective Function 1: NBS

$$\text{NBS: maximize } \prod_a (\pi_a(V_a^c) - \pi_a(V_a) + 1)$$

The +1 component in the NBS objective function accounts for cases where for a subset of terminals cooperation may not be profitable or the profit remains unchanged (which can be the case for concave profit functions). In that case if the term +1 was omitted from the objective function any solution -for the terminals that would cooperate- would be optimal with an objective function value equal to zero.

#### Objective Function 2: Total Profit

$$\text{MaxProfit: maximize } \sum_a (\pi_a(V_a^c))$$

#### Objective Function 3: Maximize Minimum Profit

$$\text{MaxMin: maximize } \min_a (\pi_a(V_a^c))$$

#### Objective Function 4: Maximize Minimum Profit Increase

$$\text{MaxMinDiff: maximize } \min_a (\pi_a(V_a^c) - \pi_a(V_a))$$

#### **Constraints**

A terminal can either receive or provide demand (but not both)

$$\sum_a (r_a + w_a) \leq 1, \forall a \in I$$

Demand at any terminal cannot exceed capacity (this constraint is not necessary and can be dropped in cases of monotonically increasing profit function for any of the terminals)

$$V_a^c \leq C_a, \forall a \in I$$

Profit for any terminal under any cooperation scenario will be greater or equal to its profits under the no cooperation scenario

$$\pi_i(V_a^c) - \pi_i(V_a) \geq 0, \forall a \in I$$

Profit under cooperation for terminal  $a \in I$

$$\pi_i(V_a^c) = hc_i(V_a) + \sum_b x_{ba} pf_b^c - \sum_b x_{ab} hf_a - hc_i(V_a^c) \forall a \in I$$

$hc_i(V_a^c) = chci * V_a^c$  handling cost is equal to container handling cost time the number of containers

$chci \geq g_{id}(V_a^c) = int_{id} + slope_{id} V_a^c, \forall d \in D$  where  $g_{id}$  is the linear approximation function for the marginal container handling cost, D: number of linear segments

Volume (TEUs) transferred from terminal  $a \in I$  to a terminal  $b \in I$  must be less than or equal to the demand at terminal  $a \in I$  under no cooperation

$$\sum_b x_{ab} \leq w_a V_a, \forall a \in I$$

Volume handled at terminal  $a \in I$  under cooperation

$$V_a^c = V_a + \sum_b x_{ba} - \sum_a x_{ab}, a \in I$$

Containers transferred to terminal  $a \in I$  cannot exceed the available demand at all the other terminals

$$\sum_b x_{ba} \leq r_a \left( \sum_{b \neq a} V_b - V_a \right), \forall a \in I$$

Handling fee of transferred demand is (100-p)% of the handling fees at the origin terminal (under no cooperation).

$$pf_a^c \leq p * hf_b(V_a) \forall a \in I, p \leq 1$$

Estimation of profit increase (handling fees portion) for demand diverted to terminal  $a \in I$

$$prg_a = \sum_b x_{ab} pf_{ab}^c, \forall a \in I$$

Estimation of profit loss (handling fees portion) for demand diverted from terminal  $a \in I$

$$prl_a = \sum_b x_{ba} hf_a \quad \forall a \in I$$

Total volume handled before is equal to total volume handled after

$$\sum_a V_a^c = \sum_a V_a$$

### 3.3 VESSEL BASED FORMULATION (VEBF)

Let  $J_i$  be the set of vessels served at terminal  $i \in I$  under no cooperation,  $x_{ji}, y_{ji}$  be the vessel to terminal assignment before and after cooperation,  $V_j$  be the volume of vessel  $j \in J$ ,  $V_i = \sum_{j \in J_i} x_{ji} V_j$  volume served at terminal  $i \in I$  before cooperation,  $V_i^c = \sum_{j \in J_i} y_{ji} V_j$  volume served at terminal  $i \in I$  after cooperation,  $hf_i^c, i \in I$  handling fee per container for demand originating from terminal,  $r_i = 1, i \in I$  if vessels are transferred to terminal  $i \in I$ ,  $w_i = 1, i \in I$  if vessels are not transferred from terminal  $i \in I$ , and  $M = |J|$ .

Objective Function 1: NBS

$$NBS: \text{maximize } \prod_i (\pi(V_i^c) - \pi_i(V_i) + 1)$$

Objective Function 2: Total Profit

$$MaxProfit: \text{maximize } \sum_i (\pi(V_i^c))$$

Objective Function 3: Minimum Profit

$$MaxMin: \text{maximize } \min_i (\pi(V_i^c))$$

Objective Function 4: Minimum Profit Increase

$$MaxMinDiff: \text{maximize } \min_i (\pi(V_i^c) - \pi_i(V_i))$$

**Constraints**

Every vessel is served at one terminal (under cooperation)

$$\sum_{i \in I} y_{ji} = 1, \forall i \in I$$

Volume at terminal  $i \in I$  under cooperation

$$V_i^c = \sum_j y_{ji} V_j, \forall i \in I$$

Profit increase/loss of terminal  $i \in I$  under cooperation

$$\pi(V_i^c) = \pi_i(V_i) + prg_i - prl_i - hc_i(V_i^c), \forall i \in I$$

Estimate profit increase if demand is diverted to terminal  $i \in I$

$$prg_i = \sum_{j \in J, \gamma \neq i, \gamma \neq i} y_{ji} hf_{\gamma}^c V_j, \forall i \in I$$

Estimate profit loss if demand is diverted from terminal  $i \in I$

$$prl_i = \sum_{j \in J, \gamma \neq i} y_{j\gamma} hf_i^c V_j, \forall i \in I$$

Demand at any terminal cannot exceed capacity (this constraint can be removed)

$$\sum_j y_{ji} V_j \leq C_i, \forall i \in I$$

Profit for any terminal under any cooperation scenario must be greater or equal to its profits under the no cooperation scenario

$$\pi(V_i^c) - \pi_i(V_i) \geq 0, \forall i \in I$$

Handling fee per container of demand that moved cannot exceed a percentage of the handling fee at the origin terminal  $b$ .

$$hf_a^c \leq p * hf_a \quad \forall a \in I$$

A terminal can either receive or provide vessels (but not both)

$$\sum_a (r_a + w_a) \leq 1$$

If a vessel is not transferred to a terminal  $i \in I$  make those  $y$ 's zero

$$\sum_{j \in J, \gamma \neq i, \gamma \neq i} y_{ji} \leq Mr_i, \forall i \in I$$

A vessel is not transferred from a terminal  $i \in I$  make those  $y$ 's zero

$$prl_i = \sum_{j \in J_i, \gamma \neq i} y_{j\gamma}, \leq Mw_i \forall i \in I$$

Demand at any terminal cannot exceed capacity (this constraint is not necessary and can be dropped in cases of monotonically increasing profit function for any of the terminals)

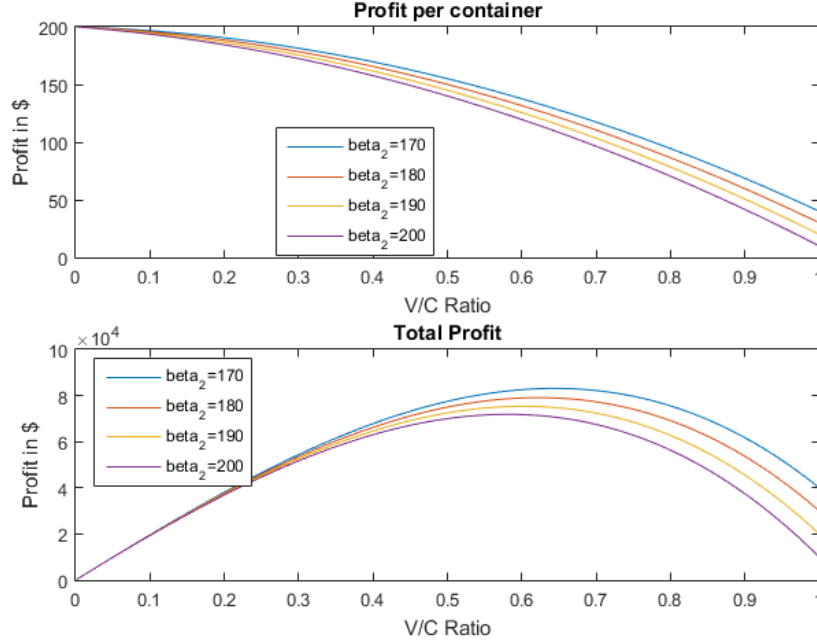
$$V_i^c \leq C_i, \forall i \in I$$

We developed thirty (30) data sets with varying demands (i.e., V/C ratios) for three terminals with the same capacity based on the uniform distributions shown in Table 6. Note that these demand levels are for a planning period. In other words, T3 might have the low demand and T1 the high demand for some periods of the year and vice versa. For each one of the thirty data sets we evaluated both model formulations for four different profit functions (shown in Figure 3) obtained by varying the cost function coefficient  $\beta_2$ , and two different cooperation cases: i) Cooperation Case 1 where terminals one (T1) and three (T3) cooperate, and ii) Cooperation Case 2 where terminals two (T2) and three (T3) cooperate.

**Table 6: Numerical experiments input data.**

|                            | T1                    | T2        | T3         |
|----------------------------|-----------------------|-----------|------------|
| Demand                     | U[10, 25]             | U[35, 65] | U[90, 100] |
| Capacity                   | 12000                 | 12000     | 12000      |
| Vessels                    | 5                     | 5         | 10         |
| $\beta_1, \beta_2, pf_i$   | [10, $\beta_2$ , 250] |           |            |
| $\alpha_1, \alpha_2, pc_i$ | [110, 87, 50]         |           |            |
| $\beta_2$                  | [170, 180, 190, 200]  |           |            |

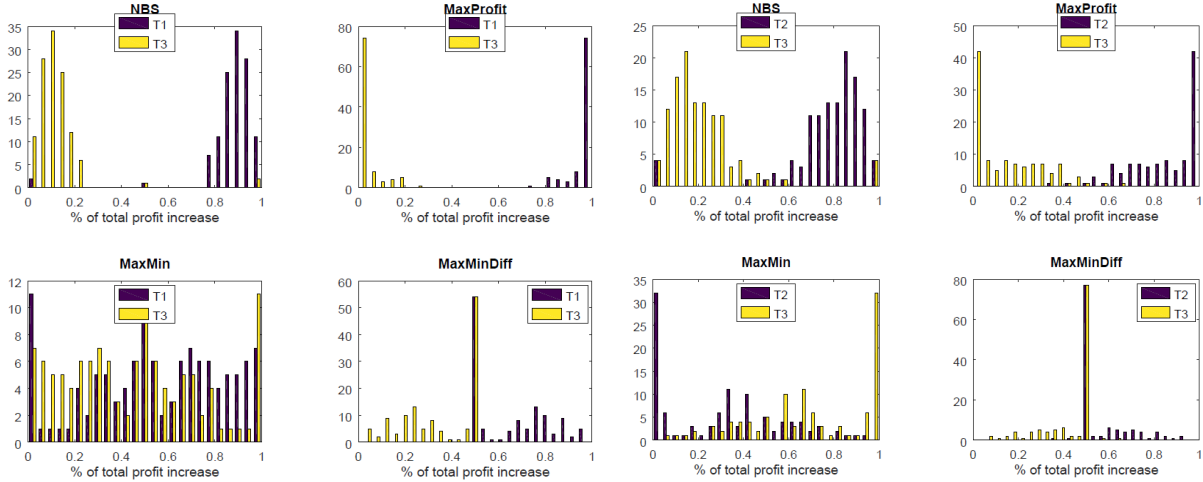
The four profit functions differ on the V/C ratio point where the terminal's productivity reaches its maximum efficiency (after which point any additional demand handled will result in a profit reduction). Note that the case of terminals T1 and T2 cooperating is not considered as their V/C ratios are too low to support cooperation (i.e., profits before cooperation lie on the left side of the maximum of the profit function). In this study BARON (Tawarmalani and Sahinidis, 2005) was used for both models. All the data and model formulations are available upon request. Next, we present a discussion on the results from the 480 data sets [(thirty datasets) x (four profit functions) x (two cooperation cases) x (two problem formulations)].



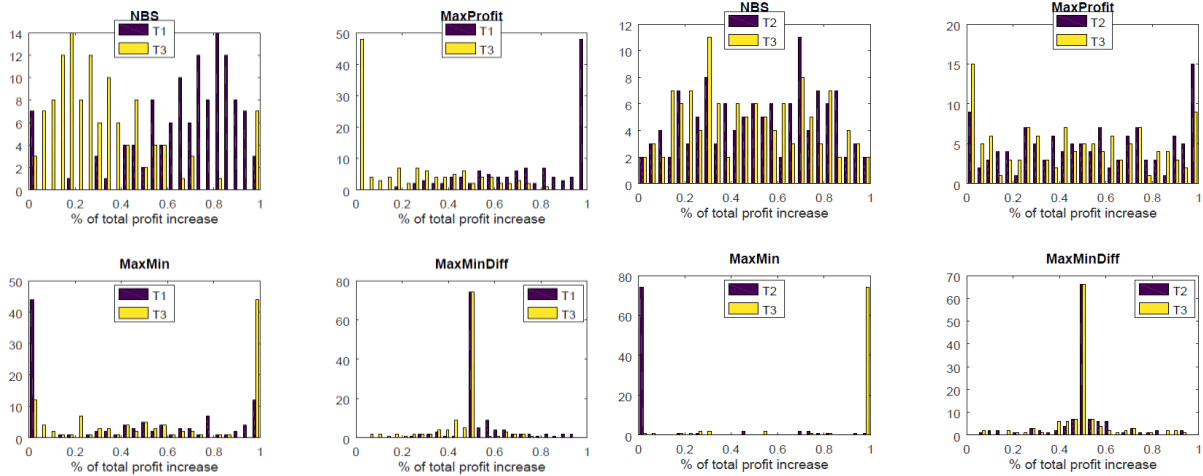
**Figure 3: Profit functions (per container and total).**

### 3.4 PROFIT DISTRIBUTION COMPARISON

Figure 4 and Figure 5 show histograms of the total profit share (%) of each terminal pair for the two cooperation cases (terminals T1 and T3, and terminals two T2 and T3), for both model formulations (vessel and volume based), and the four cooperation policies (NBS, MaxProfit, MaxMin, and MaxMinDiff) respectively. For example, the top left graph in Figure 4 shows the histograms of the total profit share of terminals T1 (yellow bars) and T3 (blue bars) for the VeBF and the NBS cooperation policy. As expected, the MaxMinDiff results in the most uniform profit share but, as we will see in the next subsection, this policy also results in the smallest total and per terminal profit increase. The NBS and MaxProfit policies favour the terminal with the lowest V/C ratio (i.e., terminals T1 and T2) with NBS exhibiting a more uniform distribution than MaxProfit. The MaxMin policy provides the worst (overall) profit distribution among the terminals, favouring the ones with the highest V/C ratio (except for the VoBF for cooperation case of terminals T1 and T3). Next, we present results and discussion on the profit size differences for the terminals, the four cooperation policies, and two formulations.



**Figure 4: Total profit increase distribution among terminals by objective function (VoBF).**



**Figure 5: Total profit increase distribution among terminals by objective function (VeBF).**

### 3.5 COOPERATION POLICY COMPARISON: PROFIT INCREASE

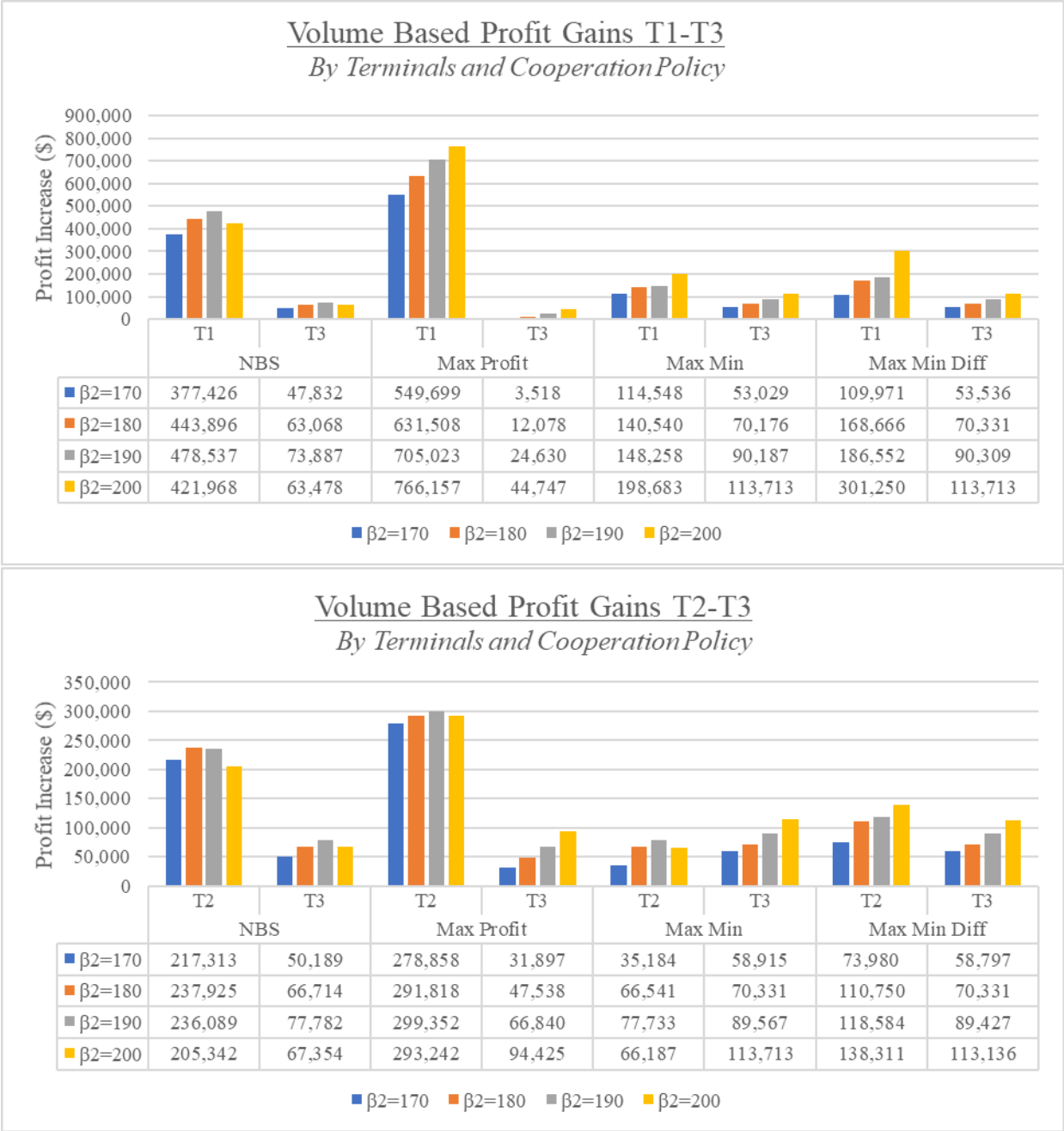
Figure 6 and Figure 7 show the mean profit increase for each terminal under each cooperation policy. In the case of the VoBF, all four policies provide higher profit increases for the terminals with the lower V/C ratio (i.e., terminals one and two) with the exclusion of the MaxMin policy for the T2-T3 terminal cooperation case. That is not the case with the VeBF where for the NBS, MaxProfit, and MaxMin policies T3 profits increase and T1 and T2 profits decrease with the increase of parameter  $\beta_2$ . We also observe that, the NBS policy, provides a better balance of profit increase amongst the terminals, except for the VoBF for cooperation case 2 and the VeBF for the cooperation case 1 (both for  $\beta_2=200$ ). Note that the differences seem to dissipate when the VeBF is applied and the difference of V/C ratios between the cooperating terminals decrease. Next, we present a comparison of the VoBF and VeBF with regards to profit increases (total and by terminal).



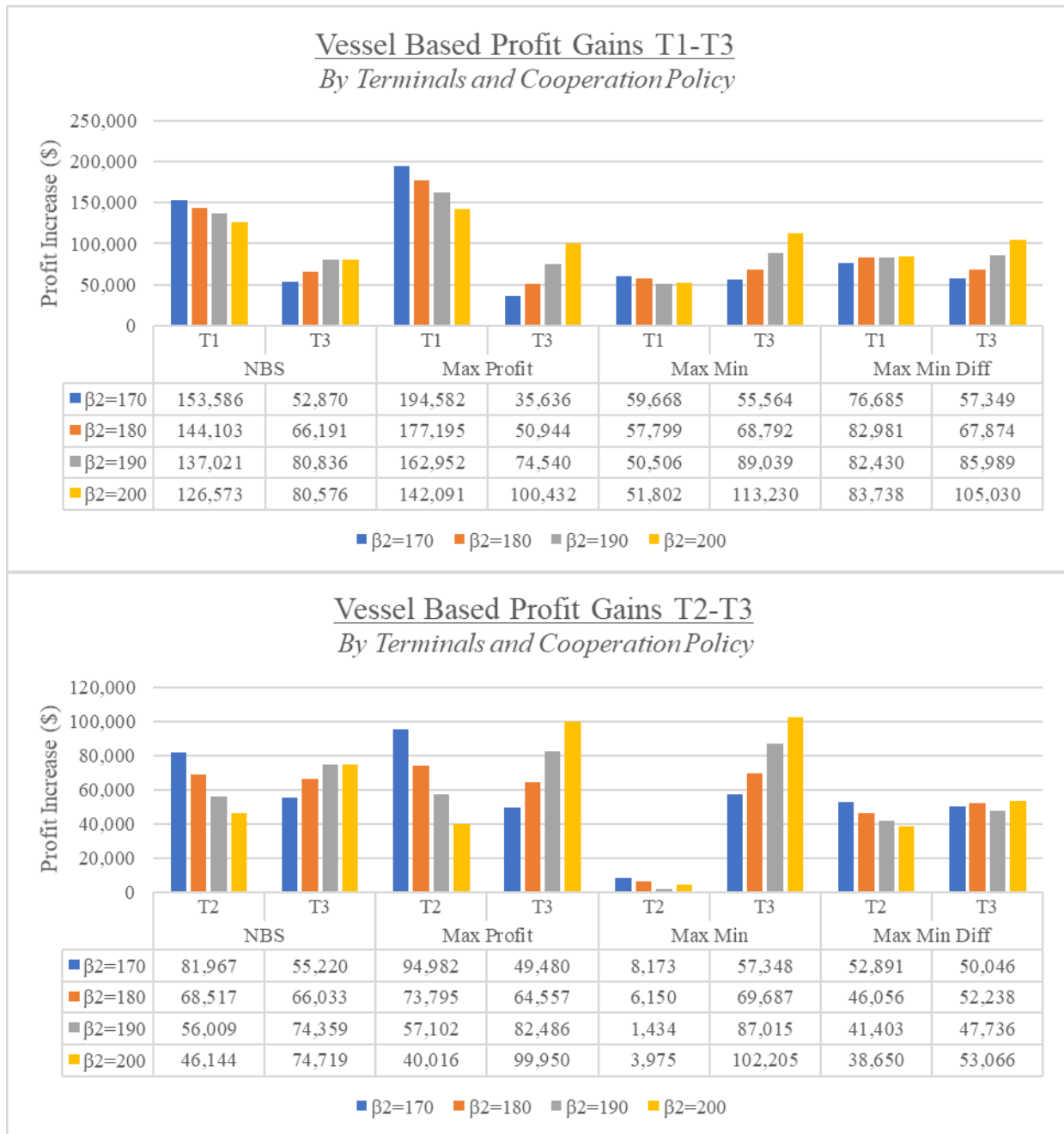
### 3.6 VOLUME TO VESSEL FORMULATION COMPARISON

Table 7 shows the percentage of the average profit increase difference of the VoBF to VeBF for each terminal, cooperation policy, and profit function. For example, T1 exhibits 59% higher profits increase under the VoBF for the NBS policy and  $\beta_2=170$ . From these results, we observe the following:

- i. VoBF overestimates the total profit increase and the profit increase of the terminals with the low V/C ratio;
- ii. In terms of total profit MaxMinDiff and MaxMin exhibit the smallest overestimation, while NBS and MaxMin policies exhibit the highest with similar ranges;
- iii. For the MaxMin and MaxMinDiff policies the overestimation increases with the  $\beta_2$  coefficient;
- iv. The VoBF underestimates the profit increase of the terminal with the highest V/C ratio in both NBS and MaxMin policies (in most of the cases);
- v. The MaxProfit policy VoBF exhibits the highest profit increase underestimation for the terminal with the highest V/C ratio (i.e., terminal three) in the cooperation case of terminals 1 and 3.



**Figure 6: Individual terminal profit increase by cooperation policy (VoBF).**



**Figure 7: Individual terminal pprofit increase by cooperation policy (VeBF).**

**Table 7: VoBF to VeBF: mean profit increase difference (by terminal and cooperation policy).**

| Mean Profit Increase Difference: VoBF to VeBF (T1 & T3) |     |      |       |           |       |       |        |     |       |            |     |       |
|---|-----|------|-------|-----------|-------|-------|--------|-----|-------|------------|-----|-------|
|   | NBS |      |       | MaxProfit |       |       | MaxMin |     |       | MaxMinDiff |     |       |
|   | T1  | T3   | Total | T1        | T3    | Total | T1     | T3  | Total | T1         | T3  | Total |
| $\beta_2=170$   | 59% | -11% | 51%   | 65%       | -913% | 58%   | 48%    | -5% | 31%   | 30%        | -7% | 13%   |
| $\beta_2=180$   | 68% | -5%  | 59%   | 72%       | -322% | 65%   | 59%    | 2%  | 40%   | 51%        | 3%  | 26%   |
| $\beta_2=190$   | 71% | -9%  | 61%   | 77%       | -203% | 67%   | 66%    | 1%  | 41%   | 56%        | 5%  | 29%   |
| $\beta_2=200$   | 70% | -27% | 57%   | 81%       | -124% | 70%   | 74%    | 0%  | 47%   | 72%        | 8%  | 38%   |
| Mean Profit Increase Difference: VoBF to VeBF (T2 & T3) |     |      |       |           |       |       |        |     |       |            |     |       |
|   | NBS |      |       | MaxProfit |       |       | MaxMin |     |       | MaxMinDiff |     |       |
|   | T2  | T3   | Total | T2        | T3    | Total | T2     | T3  | Total | T2         | T3  | Total |
| $\beta_2=170$   | 62% | -10% | 49%   | 66%       | -55%  | 54%   | 77%    | 3%  | 30%   | 29%        | 15% | 20%   |
| $\beta_2=180$   | 71% | 1%   | 56%   | 75%       | -36%  | 59%   | 91%    | 1%  | 45%   | 58%        | 26% | 37%   |
| $\beta_2=190$   | 76% | 4%   | 58%   | 81%       | -23%  | 62%   | 98%    | 3%  | 47%   | 65%        | 47% | 50%   |
| $\beta_2=200$   | 78% | -11% | 56%   | 86%       | -6%   | 64%   | 94%    | 10% | 41%   | 72%        | 53% | 58%   |

Note: Red cells indicate higher profit increase by the VeBF

### 3.7 TERMINAL EFFICIENCY IMPACT

For the same 480 datasets we re-run the models but with different handling fees and cost functions parameters (shown in Table 8) for each terminal. We assumed that the intercept of the handling fees and cost functions (i.e.,  $pf_i$  and  $pc_i$ ) decrease and increase respectively with the V/C ratio (i.e., terminal one will have a higher handling cost function intercept and a lower handling fee function coefficient when compared to terminals two and three). These assumptions are meant to reflect lower efficiencies and negotiating power (with the liner shipping companies) for the terminals with the lower V/C ratios and vice versa. For the remainder of this subsection we will refer to these terminals as lower efficiency terminals and to the terminals used in the previous section as high efficiency terminals.

**Table 8: Parameters of handling cost and fees functions by terminal.**

| Handling Cost and Fee Functions Parameters | T1              | T2 | T3 |
|--|-----------------|----|----|
| $[pf_1, pf_2, pf_3]$                       | [200, 225, 250] |    |    |
| $[pc_1, pc_2, pc_3]$                       | [70, 60, 50]    |    |    |

From these numerical experiments, we present results (in Table 9) that compare the profit increase differences between the low and high efficiency terminals for each terminal, as a percentage of their total profit increase. For example, in Table 9 for the VeBF and NBS policy high efficiency terminal T1 (i.e.,  $pf_1=250$ ,  $pc_1=50$ ) has a 9% higher share of the total profit increase when compared to the low efficiency terminal one (i.e.,  $pf_1=200$ ,  $pc_1=70$ ). It is notable that terminal three, which has the highest efficiency exhibits a loss when cooperating with

terminals with lower efficiency for both problem formulations and all policies except for certain cases of the MaxMin policy (for certain values of parameter  $\beta_2$ ).

**Table 9: Profit increase difference (as a percentage of total profit increase) by terminal (same and different handling fees, cost, and profit functions).**

|               | NBS |      | Max Profit |      | Max Min |      | Max Min Diff |      |
|---------------|-----|------|------------|------|---------|------|--------------|------|
|               | T1  | T3   | T1         | T3   | T1      | T3   | T1           | T3   |
| <b>VeBF</b>   |     |      |            |      |         |      |              |      |
| $\beta_2=170$ | 9%  | -9%  | 11%        | -11% | -23%    | 23%  | 5%           | -5%  |
| $\beta_2=180$ | 12% | -12% | 13%        | -13% | -17%    | 17%  | 6%           | -6%  |
| $\beta_2=190$ | 16% | -16% | 16%        | -16% | -11%    | 11%  | 8%           | -8%  |
| $\beta_2=200$ | 20% | -20% | 20%        | -20% | 0%      | 0%   | 7%           | -7%  |
| <b>VoBF</b>   |     |      |            |      |         |      |              |      |
| $\beta_2=170$ | 8%  | -8%  | 8%         | -8%  | -12%    | 12%  | 0%           | 0%   |
| $\beta_2=180$ | 9%  | -9%  | 10%        | -10% | -5%     | 5%   | 10%          | -10% |
| $\beta_2=190$ | 11% | -11% | 11%        | -11% | -2%     | 2%   | 6%           | -6%  |
| $\beta_2=200$ | 13% | -13% | 13%        | -13% | 6%      | -6%  | 12%          | -12% |
| <b>VeBF</b>   |     |      |            |      |         |      |              |      |
| $\beta_2=170$ | 8%  | -8%  | 8%         | -8%  | -7%     | 7%   | 6%           | -6%  |
| $\beta_2=180$ | 9%  | -9%  | 12%        | -12% | 0%      | 0%   | -1%          | 1%   |
| $\beta_2=190$ | 10% | -10% | 10%        | -10% | -2%     | 2%   | 3%           | -3%  |
| $\beta_2=200$ | 12% | -12% | 9%         | -9%  | 4%      | -4%  | 4%           | -4%  |
| <b>VoBF</b>   |     |      |            |      |         |      |              |      |
| $\beta_2=170$ | 10% | -10% | 11%        | -11% | -2%     | 2%   | 3%           | -3%  |
| $\beta_2=180$ | 12% | -12% | 14%        | -14% | 5%      | -5%  | 10%          | -10% |
| $\beta_2=190$ | 15% | -15% | 17%        | -17% | 21%     | -21% | 9%           | -9%  |
| $\beta_2=200$ | 18% | -18% | 20%        | -20% | 11%     | -11% | 9%           | -9%  |

Note: Red cells indicate that the models with the same cost, handling fee and profit functions for all terminals are lower



## **4.0 DEVELOPMENT OF WORKSHOP FOR COOPERATION AND CO-OPETITION STRATEGIES AT SEAPORTS**

In this task the research team developed the syllabus and material (PowerPoint presentations, exercises, and reading material for participants) for a one-day workshop on cooperation, competition and co-opetition in the maritime industry. The workshop is meant to provide an overview of the maritime transportation industry and its stakeholders with strong reference to the cooperation, competition and co-opetition aspects between the liner shipping industry and the port sector. The goal of the workshop is for the participants to obtain a good understanding of the concepts of maritime transportation, (liner, bulk, specialized), pricing and freight rates, market cycles, port functions, players and stakeholders, port management and ownership models (container, dry bulk and liquid bulk), and terminal key performance indicators. The syllabus and materials for the workshop can be made available to non-workshop participants after request.

## 5.0 CONCLUSIONS AND FUTURE RESEARCH

In this study, we have reviewed literature by focusing on seaport and container terminal cooperation, competition or both with other stakeholders, that uses game theory models. In the reviewed literature various topics had been discussed when considering port, terminal cooperation, competition or both: service level differentiation in combination with and without shipping distances; port ownership with and without level of service differentiation; pricing policies, capacity utilization, and comparison various cooperation policies, effects of service level differentiation in inter- and intra-port competition, also when considering transshipment cargo; competition between multi-user terminals; terminal concession awarding; port capacity investments when ports set prices under various types of demand. Reviewed studies also considered seaport and container terminal competition, cooperation or both including government number of topics discussed: port regulation under different scenarios; port ownership; emission control strategies; pricing and investment decisions between ports with hinterland congestion under various scenarios. Also, the reviewed literature included liner ship and port cooperation and competition where studies focus on horizontal and vertical interactions between liners and ports, hub ports, and hub-spoke ports including game-theoretic network design models.

In addition to the reviewed literature we have also presented a conceptual and mathematical framework with complexity analysis for port, container terminals and liner shipping alliance cooperation and competition, using a two-stage Stackelberg game, where the shipping lines in alliance act as leaders by minimizing shipping costs and terminal fees, and the container terminals act as followers by making decisions compete with each other or to engage in cooperation with other terminal by utilizing each other's capacities with objective to maximize profit. Following model is an extension of (Pujats et al., 2018), where authors evaluated and compared four different cooperation policies, where terminals share available demand and capacity.

Further, authors suggested that future research regards to port, container terminal or both cooperation and competition could include a comparison of competition strategy with cooperation strategy of ports serving partially overlapping hinterland in a situation when ports compete in price and geographic location has been considered and also including different alliance scenarios (Zhou, 2015). Incorporation of more practical issues in the models that would help model robustness (e.g., global port operators operating in both ports, or the same municipal shares in both ports) was suggested by (Cui and Notteboom, 2018). Investigation of additional costs for transshipment containers that will have to be moved between terminals or have to be loaded on specific vessels at the port of origin was proposed by (Pujats et al., 2018). Kaselimi et al., 2011 noted that not all port authorities and terminal operators are profit-maximizing firms, some port authority objective is more oriented toward welfare maximization. Thus, future research could focus on adapting the model to incorporate competing welfare maximizing port authorities and competing profit maximizing terminal operators. Luo et al., 2012 considered that the further research on port capacity investment decisions could include examination the optimal pricing strategies where two terminals are managed by the same operator but have different operating costs and compete with other terminal operators serving the same hinterland. Also,



analysis of the impact of port capacity investment decisions on both the port development policy and shipping operations could be explored.

From the reviewed literature where studies considered government, port and, container terminal competition, cooperation or both a further research direction suggested by (Zheng and Negenborn, 2014) would be to describe the situation on port regulation with uncertain demands, multiple port coexistence and competition in one province and also designing collusion proof port regulation scheme. Effect carrier market power and scale economies on the consequences of transshipment routes and port competition, and the resulting implications on privatization was another suggested future research study direction by (Czerny et al., 2014). Future research of emission control in port areas identified by (Cui and Notteboom, 2017) could include investigation how the optimal private level and emission tax will be affected by a third market (transit market). Local governments' incentives to form various types of coalitions between ports and shippers was identified by (Basso et al., 2013) as another potential future research area. Matsushima and Takauchi, 2014 considered that government, port and, manufacturing firm competition future research could be competition among international ports.

Some of the future avenues to model port and liner shipping competition, cooperation or both were considered by (Song et al., 2016), were authors highlighted that future work on port and liner shipping competition, cooperation or both could involve modeling access to multimodal transportation, port location, and port capacity provision. Also, authors noted that the cooperation and revenue allocation between port and liner could be another research direction. Angeloudis et al., 2016 suggested one potential research direction would be to explore the possibility that shipping lines or alliances differentiate their networks and thus relax competition among themselves, and the possibility for each shipping line or alliance to optimize the cost structure of its network.

From the reviewed studies, one of the most suggested points for future research is to include uncertain or stochastic demand, only two authors (Do et al., 2015, Ishii et al., 2013) have used this assumption in their studies. Data unavailability is another major issue noted in the reviewed literature, which restricts researchers to complete and more realistic model development. Studies that do have empirical analysis more times than not do not have full information and have to make some assumptions and approximations (Asgari et al., 2013; Nguyen et al., 2015; Ignatius et al., 2018; Saeed and Larsen, 2010a; Park and Suh, 2015; Anderson et al., 2008; Do et al., 2015; Tuljak-Suban, 2017).



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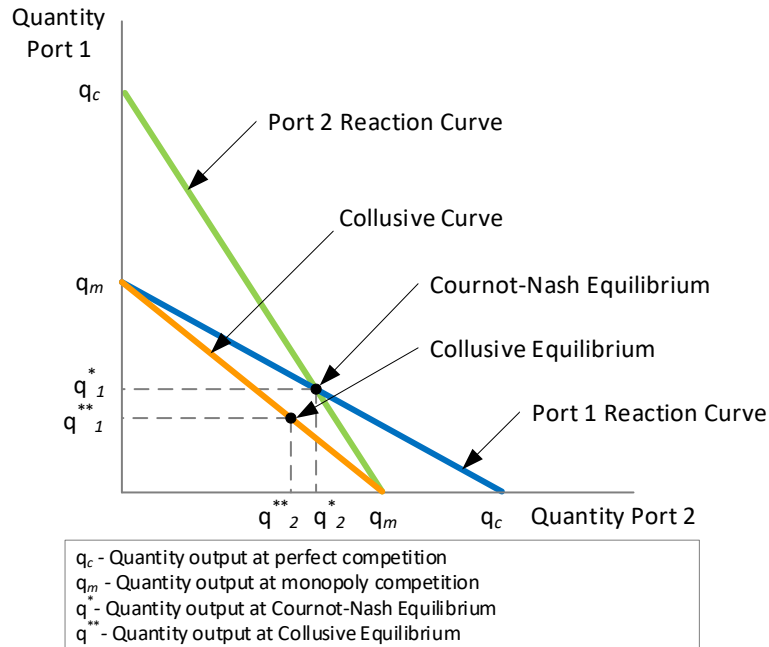
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## APPENDIX A: EXAMPLE FORMULATIONS FROM THE LITERATURE

|   |
|---|
| <b>PORT COMPETITION AND COOPERATION USING COURNOT MODEL</b> (Wang et al., 2012)   |
| <b>Notation</b>   |
| <p><math>p_i</math> – price at port <math>i</math><br/> <math>c_i</math> – cost at port <math>i</math><br/> <math>q_i</math> – quantity output at port <math>i</math><br/> <math>a_i</math> – demand intercept at port <math>i</math><br/> <math>b_i</math> – slope of demand curve for port <math>i</math><br/> <math>s</math> – the degree of substitutability between the service provided</p> |
| <b>Cournot Duopoly with Differentiated Services</b>   |
|   |
| <b>Figure A-1: Conceptual model Cournot duopoly with differentiated services.</b>   |
| <b>Collusion</b>  |
|   |
| <b>Figure A-2: Conceptual model Collusion.</b>  |
| <b>Cournot-Nash Equilibrium and Collusive Equilibrium</b>   |



**Figure A-3: Conceptual model Hotelling game.**

**Cournot-Nash Equilibrium**

$$q_i = \frac{2b_j(a_i - c_i) - s(a_j - c_j)}{4b_i b_j - s^2}$$

$$p_i = \frac{b_i(2b_j a_i - s a_i) + s b_i c_j + (2b_i b_j - s^2)c_i}{4b_i b_j - s^2}$$

$$\pi_i = \frac{b_i[2b_j(a_i - c_i) - s(a_j - c_j)]^2}{(4b_i b_j - s^2)^2}$$

**Collusive Equilibrium**

$$q_i = \frac{b_j(a_i - c_i) - s(a_j - c_j)}{2(b_i b_j - s^2)}$$

$$p_i = \frac{a_i + c_i}{2}$$

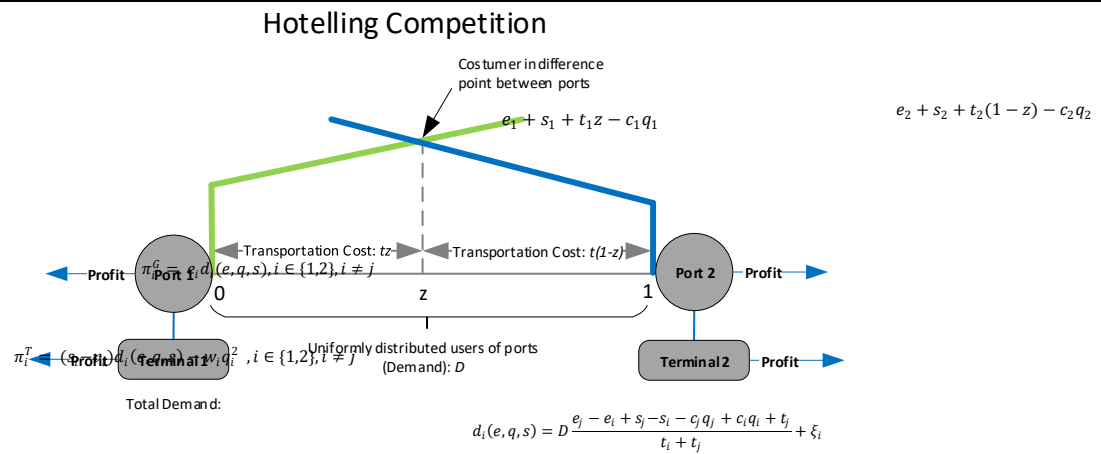
$$\pi_i = \frac{(a_i - c_i)[b_j(a_i - c_i) - s(a_j - c_j)]}{4(b_i b_j - s^2)}$$

**PORT COMPETITION USING TWO STAGE HOTELLING MODEL (Yu et al., 2016)**

**Notation**

- $e_i$  – cargo fee at port  $i$
- $z$  – indifference point, where the customer is indifferent in choosing between two container terminals
- $D$  – total footloose transferable demand
- $d_i$  – total demand for container terminal  $i$
- $s_i$  – service price at terminal  $i$
- $q_i$  – service quality output at terminal  $i$
- $t_i$  – unit transportation cost to terminal  $i$
- $c_i$  – customers unit intangible benefit choosing terminal  $i$
- $\xi_i$  – exclusive demand of terminal  $i$
- $w_i$  – service quality investment cost coefficient of terminal  $i$
- $w_i q_i^2$  – service quality level of terminal  $i$
- $v_i$  – the operational cost coefficient of terminal  $i$

**Hotelling model**



**Figure A-4: Conceptual model Hotelling competition.**

**Terminal Service Price Equilibrium**

$$s_i^*(e, q) = \frac{e_j - e_i - c_j q_j + c_i q_i + t_j + v_i}{3} + \frac{2(v_i + t_j)}{3} + \frac{(t_i + t_j)(2\xi_i + \xi_j)}{3D}, i \in \{1,2\}, i \neq j$$

**Terminal Service Quality Equilibrium**

$$q_i^*(e) = \frac{((R_i + c_i R_i R_j)(e_i - e_j) - R_i T_i + c_j R_i R_j T_i)}{c_i c_j R_i R_j - 1}$$

where,

$$R_i = \frac{D c_i}{9 w_i (t_i + t_j) - D c_i^2}$$

$$T_i = t_i + v_j + 2t_j - v_i + \frac{(t_i + t_j)(2\xi_i + \xi_j)}{D}$$

**Port Government Cargo Fee Equilibrium**

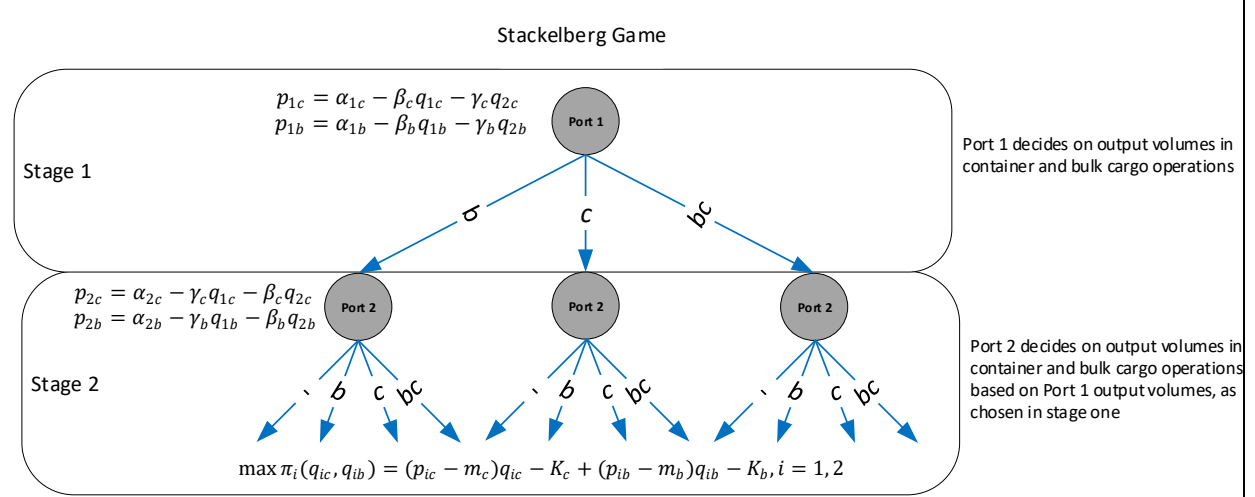
$$d_i^*(e) = \frac{D}{3(t_i + t_j)} \left( \frac{(e_i - e_j)(1 + c_i R_i + c_j R_j + c_i c_j R_i R_j) + c_i R_i T_i - c_j R_j T_j + c_i c_j R_i R_j (T_i - T_j)}{1 - c_i c_j R_i R_j} + v_j - v_i + t_i + 2t_j \right) + \frac{\xi_j}{3} + 2\frac{\xi_i}{3}$$

**PORT COMPETITION USING STACKELBERG COMPETITION (Zhuang et al., 2014)**

**Notation**

$j = b, c$  – bulk cargo, container cargo  
 $i = 1, 2$  – ports  
 $p_{ij}$  – port service charge  
 $q_{ij}$  – output traffic volume  
 $\alpha_{ij}$  – reservation price for port  $i$  service  $j$   
 $K_c, K_b$  – fixed costs related to port investment and operation  
 $T_{ic}, T_{ib}$  – the total cost for container port services and bulk goods port services  
 $m_c, m_b$  – marginal costs  
 $\gamma_j, \beta_j$  – the degree of competition between the two ports  
 $\begin{cases} T_{ic} = K_c + m_c q_{ic}, i = 1, 2 \\ T_{ib} = K_b + m_b q_{ib}, i = 1, 2 \end{cases}$

**Stackelberg Duopoly with Differentiated Services**



**Figure A-5: Conceptual model Stackelberg game.**

**Outcome (b, -), (c, -), (bc, -), (b, c), (c, b) Equilibrium**

$$q_{1c} = \frac{\alpha_{2b} - m_c}{2\beta_c}, q_{1b} = \frac{\alpha_{1b} - m_b}{2\beta_b}$$

$$\pi_1 = \frac{(\alpha_{1c} - m_c)^2}{4\beta_c} + \frac{(\alpha_{1b} - m_b)^2}{4\beta_b} - K_b - K_c$$

**Outcomes (b, b), (c, c), (bc, bc) Equilibrium**

$$q_{1c} = \frac{1}{4\beta_c^2 - 2\gamma_c^2} ((2\alpha_{1c}\beta_c - \alpha_{2c}\gamma_c) - (2\beta_c - \gamma_c)m_c)$$

$$q_{2c} = \frac{1}{2\beta_c(4\beta_c^2 - 2\gamma_c^2)} ((4\alpha_{2c}\beta_c^2 - 2\alpha_{1c}\beta_c\gamma_c - \alpha_{2c}\gamma_c^2) - (4\beta_c^2 - 2\beta_c\gamma_c - \gamma_c^2)m_c)$$

$$\pi_1 = \frac{1}{4\beta_c(4\beta_c^2 - 2\gamma_c^2)} ((2\alpha_{1c}\beta_c - \alpha_{2c}\gamma_c) - (2\beta_c - \gamma_c)m_c)^2 - K_c$$

$$\pi_2 = \frac{1}{4\beta_c(4\beta_c^2 - 2\gamma_c^2)^2} ((4\alpha_{2c}\beta_c^2 - 2\alpha_{1c}\beta_c\gamma_c - \alpha_{2c}\gamma_c^2) - (4\beta_c^2 - 2\beta_c\gamma_c - \gamma_c^2)m_c)^2 - K_c$$

