Faculty of Business and Economics

Essays on competition and cooperation in the port and shipping industry

Essays over concurrentie en samenwerking in de haven- en scheepvaartindustrie

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Abstract

The shipping and port industry involves a complex interplay between cooperation and competition. In the past decades, the market has witnessed unprecedented scenes, including not just the cut-throat competition among shipping lines, ports, and maritime transport chains but also the formation of giant shipping alliances, consolidation in shipping, mergers, acquisitions, and joint ventures in the port operating market, and the mergers of corporatized or privatized managing bodies of ports. Understanding the multidimensionality in the strategy of competition and cooperation (co-opetition) is beneficial to the competitiveness of both private firms and public organizations. So, this dissertation attempts to make sense of the complexity, where various actors are involved, mainly without a clear overarching purpose or deliberate joint strategy under certain circumstances, and understand the economic motivations and strategy behind them.

This thesis discusses several cases in the context of port/shipping cooperation and competition. As this is a paper-based PhD dissertation, all chapters cover various aspects of the overall PhD theme of competition and cooperation in the ports and shipping industry. However, all chapters – some of which are based on papers already published in scholarly journals - can be read independently as standalone papers.

This PhD dissertation is structured as follows. Chapter 1 discusses an incentive framework to solve the collaboration problem between shipping lines and railway operators in the port area. This chapter presents a conceptual framework for vertical collaboration in the maritime port-hinterland transport chain. Chapter 2 investigates the benefit allocation of voyage integration/synchronization among cooperating shipping lines. Chapter 3 analyzes the effects of port objective orientation of port authority and service differentiation on capacity, service price, profit, and social welfare under cooperating or competing scenarios, which contributes to the literature about how the privatization and service differentiation will affect the decision of the port authority in competing or cooperative scenarios. Chapter 4 looks at how the capacity expansion (vertical integration between port and shipping line) will affect the goal of different participants, including port operators, port authorities, and the integrated shipping line with its rivals. Chapter 5 presents an adaptation of the model presented in Chapter 3 to investigate imposing an emission control tax on vessels and port operations in the port area in the context of port competition/cooperation between a private port and a landlord port.

Samenvatting

De scheepvaart- en havenindustrie kent een complex samenspel van samenwerking en concurrentie. In de afgelopen decennia is de markt getuige geweest van ongekende taferelen, waaronder niet alleen de moordende concurrentie tussen scheepvaartmaatschappijen, havens en zeetransportketens, maar ook de vorming van reusachtige scheepvaartallianties, consolidatie in de scheepvaart, fusies, overnames en joint ventures in de havenexploitatiemarkt en de fusies van verzelfstandigde of geprivatiseerde havenbeheerders. Het begrijpen van de multidimensionaliteit in de strategie van concurrentie en samenwerking (co-opetitie) is gunstig voor het concurrentievermogen van zowel private bedrijven als publieke organisaties. Daarom probeert deze dissertatie de complexiteit te begrijpen, waarbij verschillende actoren betrokken zijn, voornamelijk zonder een duidelijk overkoepelend doel of bewuste gezamenlijke strategie onder bepaalde omstandigheden, en de economische motivaties en strategie erachter te begrijpen.

Dit proefschrift bespreekt verschillende gevallen in de context van samenwerking en concurrentie tussen havens en scheepvaart. Aangezien dit een op papier gebaseerd proefschrift is, behandelen alle hoofdstukken verschillende aspecten van het algemene PhD-thema van concurrentie en samenwerking in de havens en scheepvaartindustrie. Alle hoofdstukken - waarvan sommige gebaseerd zijn op papers die al gepubliceerd zijn in wetenschappelijke tijdschriften - kunnen echter onafhankelijk gelezen worden als op zichzelf staande papers.

Dit proefschrift is als volgt opgebouwd. Hoofdstuk 1 bespreekt een stimulerend raamwerk om het samenwerkingsprobleem tussen scheepvaartmaatschappijen en spoorwegexploitanten in het havengebied op te lossen. Dit hoofdstuk presenteert een conceptueel raamwerk voor verticale samenwerking in de maritieme transportketen tussen haven en achterland. Hoofdstuk 2 onderzoekt de verdeling van voordelen van reisintegratie/synchronisatie tussen samenwerkende rederijen. Hoofdstuk 3 analyseert de effecten van de havendoeloriëntatie van de havenautoriteit en de differentiatie van de dienstverlening op de capaciteit, de prijs van de dienstverlening, de winst en de sociale welvaart in samenwerkende of concurrerende scenario's. Dit draagt bij aan de literatuur over hoe de privatisering en de differentiatie van de dienstverlening de beslissing van de havenautoriteit in concurrerende of samenwerkende scenario's zal beïnvloeden. Hoofdstuk 4 onderzoekt hoe de capaciteitsuitbreiding (verticale integratie tussen haven en scheepvaartmaatschappij) het doel van verschillende deelnemers zal beïnvloeden, waaronder havenexploitanten, havenautoriteiten en de geïntegreerde scheepvaartmaatschappij met haar rivalen. Hoofdstuk 5 presenteert een aanpassing van het in hoofdstuk 3 gepresenteerde model om het heffen van een emissiebelasting op schepen en havenactiviteiten in het havengebied te onderzoeken in de context van havenconcurrentie/samenwerking tussen een particuliere haven en een verhuurdershaven.

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Introduction

Shipping and ports play a crucial role in generating economic growth and employment opportunities while also serving as a key for global trade. The impact of globalization, with its diverse business networks and intricate production and consumption patterns, has intensified the complexity and uncertainty of freight transport and logistics. As a result, shipping, port, and supply chain managers face an increasing challenge to respond efficiently and effectively to market trends and regulatory issues while also meeting the evolving demands of customers and reducing their environmental footprint so as to obtain competitiveness. Parola et al. (2017) identified several key drivers for (port) competitiveness moderated by the current industry trend, including the formation of shipping alliances (economies of scale in shipping), the growth of mergers and joint adventures of port operators/carriers (cooperation among ports & inter-firm network), the privatization in port industry (governance changes), the increased demand for integrated logistics (inter-firm network) and concerns on green shipping/port (green shipping/port requirement). Each driver is individually or overlappingly reflected in five chapters. New technological approaches, one of which is digitalization, also play a role in shaping port competitiveness. Digitalization is fundamentally transforming the shipping and port industry, making operations more efficient, reducing costs, improving safety, and enhancing environmental sustainability, and it also enables better data-driven decision-making (Fonseca, 2018), benefiting all stakeholders along the supply chain. Gonzales et al. (2019) summarized eight specific domains in maritime transportation that other industries consider the sign of leading-edge of digitalization: Robotics (e.g., Unmanned vehicles, Automated Guided Vehicle, Automated Loading/Unloading Technologies, etc.), Artificial intelligence (AI), Big data, Virtual reality, Internet of thing (IoT), Cloud computing, Digital security, and 3D printing.

To deal with uncertainty and complexity, shipping lines and ports can make different strategic decisions. For instance, a shipping line can choose to expand its fleet/capacity/routes, to actively compete with its rivals, or to join a mega-shipping alliance. The formation of a giant shipping alliance is a typical horizontal cooperation, which is beneficial not only for cost saving from the economies of scale (Parola et al. 2017) but also for gaining bargaining power against ports. As for the port industry, many ports choose to compete with other ports more actively for more market shares. However, some ports opt to cooperate, either in horizontal forms, such as forming a port group with other ports, or in vertical form (upstream/downstream), such as collaboration between the port and a member of a shipping alliance to receive a much higher chance of port of call from the alliance (Notteboom et al., 2017). By doing so, ports can countermeasure the increasing bargaining power from shipping alliances and eventually purchase even higher market shares.

The examples above imply that competition and cooperation are crucial strategic decisions for the shipping and port industry. The paragraphs below, until the motivation part, serve as a brief introduction to competition and cooperation in the shipping and port industry, describing the definition and covering several key literatures.

The unit of Analysis

➢ Cooperation

While competitive forces typically remain high, various maritime and port-related actors have made advances in implementing formal and informal cooperation schemes, in some cases leading to full integration. Examples include alliance formation and consolidation in shipping, mergers, acquisitions, and joint ventures in the port operating market, and the mergers of corporatized or privatized managing bodies of ports. The growing uncertainty and disruptions on the demand side, and social & environmental concerns in the port and shipping industry are all adding complexity to decision-making in the fields of competition and cooperation.

The notion of cooperation not only refers to the typical horizontal cooperation among shipping companies or ports. It also includes vertical integration/cooperation along the maritime supply chain, such as shipping lines with ports, which can result in cost savings, improved efficiency, and overall customer satisfaction. Types of port cooperation are observed as being significantly diverse. They differ not only between the involvement of port authorities and terminal operators but also between port functions and port locations. In addition, cooperative means vary from joint venture, merger, or acquisition to strategic alliance (Notteboom & Winkelmans, 2001; Wang et al., 2015). In certain extreme cases, encouraging more cooperation in different aspects, such as joint operations or infrastructure development, or even mergers in the context of cut-throat competition, is also a feasible solution (Song, 2003).

The competition among shipping lines, however, tends to lead to cooperation among them, forming a certain alliance and sharing slots in the common route for better bargaining power, not just against other shipping lines/alliances, but also against the ports, as the maritime industry has witnessed numerous integration processes between carriers (see Cariou, 2008; Frémont, 2009; Wang, 2015). The cooperation among the carriers primarily refers to various forms, such as liner conferences (Bennachio et al., 2007; liner conferences have been abolished in 2008 following a decision of the European Commission), alliances (see for an overview Slack et al., 2002; Notteboom et al., 2017; Ghorbani et al., 2022), and mergers (see Crotti et al., 2020). Das (2011), Panayides et al. (2011), Notteboom et al. (2017), and Cariou et al. (2021) focus on the strategic decision related to the shipping alliance, including the decision to join the alliance, selection of the right alliance partner, prerequisites of service characteristics and market strategy, cooperative mechanism design, port choice, and capacity management in alliance. Meng et al. (2012), Zheng et al. (2015), Chen et al. (2017), and Shi et al. (2020) all investigate the coordination mechanism within shipping alliances on an operational level related to synergy in alliance, including sharing and allocating of ships and slots, joint-dispatching ships, collaborative-designing route network. Panayides et al. (2002), Rau et al. (2017), and Lee (2019), from the management perspective, investigate the maintenance/stability of alliance and assessment of the performance. Furthermore, a trend in the liner shipping market has been observed that there has been an increase in mergers and cooperation agreements among the large carriers, in a more and more concentrated way, in order to achieve both strategic and operational goals. The typical mergers and acquisitions in liner shipping are the merger between Cosco and China Shipping line into (new) COSCO, the take-over of APL by CMA CGM, or the take-over of Hamburg-Süd by Maersk. The motivations behind the shipping alliance are many: liners can benefit from the economies of scale or scope, improve capacity utilization, gain access to containerships, improve service frequencies, and expand global service coverage (Cullinane et al., 2000; Parola et al., 2017; Ghorbani et al., 2022).

Vertical integration in the shipping and port industry is typically represented by shipping lines acquiring equity stakes in terminal operating companies or directly managing terminal facilities themselves for exploiting dedicated service (Slack, 1993; Haralambides et al., 2002; Soppé et al., 2009). In more recent years, some shipping lines, such as Maersk and CMA CGM, have developed far-reaching logistics integration strategies by also extending their reach into logistics, e-commerce, air freight, and other related activities (Paridaens and Notteboom, 2022). Tan et al. (2018) investigated the vertical integration between ocean carriers and inland shipping companies.

Still, terminal activities remain a key action field for carriers wanting to take steps in vertical integration. Such moves can result in a dedicated terminal, which only handles containers of the related carrier. In recent times, the semi-dedicated formula (i.e., selling spare capacity to third-party customers, which are often partners in the shipping alliance) became more and more common to achieve a higher degree of utilization of the facility, thus reducing management costs (Notteboom et al., 2017). Haralambides et al. (2002) offer a detailed analysis of the costs (e.g., diseconomies of scale in ports) and the benefits (e.g., flexibility, reliability, short turnaround time, and high efficiency) of dedicated terminals. Saeed et al. (2010) found that such an integration strategy will increase the price of port service, which is consistent with the nature of horizontal integration. Song et al. (2008) built a framework to measure terminal integration in the supply chain and its impacts on port competitiveness. Ryoo (2011) mentioned port integration can be extended to the cooperation between port-related organizations and various maritime players. Kaselimi et al. (2011) suggest some advantages that a shipping line can exploit from the dedicated terminal, including value-added services to customers and increased profit. Zhu et al. (2019) investigated the investment of shipping lines into port capacity, and the results suggest that vertical integration leads to increased port capacity, port charges, market output, and consumer surplus while reducing delay costs, despite the fact that vertical integration will damage those non-integrated rival shipping lines.

Port horizontal cooperation can also raise the competitiveness and bargaining power against the giant shipping alliance. There are many cases of port cooperation around the world, such as the cooperation among port authorities, represented by Copenhagen Malmö Port (2001) and Port of Antwerp-Bruges (2022), and the intra- or inter- port cooperation among different port operators, which are accomplished by the same global terminal operator, such as the cooperation between HongKong and Shenzhen Port (Song, 2002), and fully integration of port (port authorities and port operators were fully merged), represented by Ningbo-Zhoushan Port (2015) and other Chinese port groups at provincial level. Donselaar et al. (2010) explore the potential benefits of port authority cooperation for societal welfare and analyze the national government's role in promoting such collaboration. Wang et al. (2012) investigate the factors and conditions influencing regional port governance in South China, with a particular focus on the formation of alliances among ports serving partially overlapping hinterlands. Inoue (2018) centers on the Kobe-Osaka port alliance to evaluate its effectiveness in practice and identify associated challenges and business opportunities. Wu et al. (2018) delve into the process of port cooperation and integration in Liaoning, offering qualitative insights into the motivation and methods behind integration efforts. However, the port cooperation/integration requires careful management to ensure that it does not undermine competition. Dong et al. (2018) examined the effects of port integration in the multiport region, finding that port integration can cause lower handling charges and higher container throughput, and its numeric case is applied to the case of Ningbo-Zhoushan Port.

On the other hand, vertical integration of port and inland transport has been the subject of extensive research in port supply chains. A multitude of empirical and numerical studies have contributed to a comprehensive body of literature, spanning investigations into intermodal transport (Monios and Wilmsmeier, 2013; Gonzalez Aregall et al., 2018; Zhang et al., 2018; Liu et al., 2019; Wang et al., 2019) as well as hinterland transport (Frémont and Franc, 2010; Álvarez-SanJaime et al., 2015; Sugawara, 2017). Moreover, De Borger and De Bruyne (2011) explored the implications of vertical integration, examining scenarios involving profit-maximizing trucking firms and welfare-maximizing terminal operators, and Li et al. (2014) delved into the planning of intermodal transport linking ocean terminals and inland terminals, with a particular focus on the strategies employed by container transport operators.

- **Competition**

The notion of competition mainly refers to port competition and the competition among shipping lines/alliances.

Although the capacity and cargo volume of shipping lines/alliances have increased significantly in the past decades, their profit margin has not kept up, which is mainly due to the fierce competition among shipping lines/alliances. Be noted that even the decision to form a strategic alliance (shipping alliance) among shipping lines partially results from the fierce competition. The maritime transport of containerized cargo is often considered a highly ‘commoditized’ market as there is little differentiation possible between the services of different carriers. The level of service differentiation is particularly low among the shipping lines belonging to the same shipping alliance that jointly manage ship capacity on one or more trade routes. In the period 2009-2019, liner shipping companies were regularly confronted with decreasing profits or even losses, mainly resulting from fleet overcapacity and the associated low freight rates. While shipping lines realized record profits in the period 2020-2022 due to extremely high freight rates and supply chain issues related to the COVID-19 pandemic, low freight rates and fears for vessel overcapacity re-emerged in mid-2022 (UNCTAD, 2022; Notteboom et al., 2022).

The study on port competition has the longest history as it enjoys a central position in port development, operation, and management. Whenever ports provide similar services for the overlapping hinterland, competition naturally exists (Slack, 1985). More ports are being built in close vicinity, and better transportation facilities enable each port to access a more extensive hinterland. As a result, ports no longer have an exclusive hinterland, and competition exists among ports servicing customers in the same area. They must promote their respective competitiveness to outperform others in the competition and survive in the market (Cullinane et al., 2004; Chang and Talley, 2019). It is generally believed that port competition can help ports to keep competitiveness, but different perspectives may give opposite answers.

Observing the nature of port competition, two types can be distinguished: intra-port competition between terminal operators within a port and inter-port competition between operators/authority in neighboring port ranges or in different port ranges.

A typical example of intra-port competition is the rivalry among different container terminals in the Port of Antwerp: DP world Antwerp gateway terminal, MSC PSA European terminal, and PSA Antwerp Europa terminal. De Langen et al. (2006) provided an overview of the benefits of intra-competition, such as increasing port competitiveness, local and national economies, consumers and exporting industries, and innovation, and the authors also examined the two arguments supporting its benefits and under what conditions intra-port competition should be introduced or limited. Saeed et al. (2010) studied the intra-port competition among three container terminals located in a port in Pakistan and examined the different types of coalitions among the container terminals using a two-stage game method. Kaselimi et al. (2011) analyzed the intra-port competition among multi-user terminals by a game theoretical model with horizontally differentiated service, and they found that the exclusively dedicated terminal affects intra-port and inter-port competitions, compared to the multi-user terminals. Yip et al. (2014) suggested that the increase in inter-port competition and intra-port competition can damage terminal operators if those operators decide to expand their capacity. Wang et al. (2018) investigated how the natural disaster affects adaption investments in the context of inter- and intra-port competition and cooperation. Kavirathna et al. (2019) tested how the ownership structure of terminals (port privatization, as mentioned below) will affect intra-port competition and cooperation.

There is richer and various literature on the subject of inter-port competition, covering not only the “narrow/strict” inter-port competition regarding port selection, port productivity, and port competitiveness but also the overlapping topics on the basis of inter-port competition, such as port investment, capacity expansion, port privatization, port congestion, transport/supply chain, etc. Cullinane et al. (2005) evaluated the port competition between Shanghai and Ningbo in terms of price, service quality, and generalized cost. Yap et al. (2006) presented a case study of the port competition development in East Asia (1995-2001). Anderson et al. (2008) explored the competition between two hub ports, Busan and Shanghai, to gain insights into how a rival port would respond to the development of the focal port and whether the focal port could capture or defend market share through capacity investment. Notteboom et al. (2010) revisited the container traffic flow in Europe and found emerging issues regarding the competition in and between gateway regions. De Borger et al. (2008) utilized a two-stage game-theory model to examine the interplay between the pricing strategies of two rival ports and the capacity investment policies in both the ports and hinterland, taking the port and hinterland congestion into account. Zondag et al. (2010) applied an inter-port competition model in combination with a detailed trade model and transport network to assess the impacts of various policy measures (such as infrastructure and pricing) on the port itself, its maritime access, and its connections to the hinterland. De Oliveira et al. (2015) investigated the effects of competition on port competitiveness. Tian et al. (2015) identified changes in the competition relationship over time. Notteboom et al. (2012) examined the competitive relationships present within three major container-handling regions worldwide. Luo et al. (2012) applied a game theory model to analyze the competition between Hong Kong port and Shenzhen Port and found that the model result explained the transition of the container market. Ishii et al. (2013) applied a game-theory model under uncertain demand to examine the effects of port expansion on port charges in the context of inter-port competition. Bae et al. (2013) investigated container port competition for transshipment cargoes in a duopoly market by including the decision of port of call by shipping lines and the pricing decision by ports. Zhuang et al. (2014) utilized duopoly games to model the competition between two ports that handle two different types of cargo and revealed that inter-port competition could result in port specialization in terms of cargo type and port service choice. Zhou et al. (2015) conducted an analysis of the optimal strategy (either competition or cooperation) when dealing with new competitors. Hwang et al. (2010) found that cooperation and co-opetition can enhance the competitiveness of port clusters. Song et al. (2016) modeled the port competition with hinterland shipments and transshipments from a transport chain perspective by presenting the non-cooperative game model and the centralized game model. Besides, Song et al. (2003) extended the theory and practice of port competition by combining competition and cooperation, named port co-opetition, meaning that the ports share the marketing, sourcing, personal, and equipment, etc., but still compete for the customers and hinterland. In this field, the game-theoretical model is the most common method to analyze strategic behavior among competing ports.

- **Port privatization**

Like the research on port competition and cooperation, port privatization also contributes to port competitiveness. Since the 1980s, port privatization has been becoming increasingly common worldwide. Although the situation differs from port to port, according to the general category (ownership structure) defined by The World Bank (2007), service/tool (public) ports and landlord ports are generally considered to have a strong focus on public objectives (i.e., maximizing consumer surplus), while fully private ports will mainly focus on profits only. Generally, the higher the public/state-owned investment, the stronger the focus on the overall social welfare of the port since the investments from public sources must satisfy more diversified / combined objectives, e.g., including indirect employment linked to the port. Kullinane and Song (2002) investigated the claim that "port privatization will ultimately lead to an improvement in economic efficiency and financial and operational performance" together with its practice but concluded that port privatization is only a partial cure if implemented in isolation. Baltazar et al. (2006) proposed a matching framework that identifies and prioritizes critical contingency variables in port management and governance, checking the feasibility of port devolution in the form of port privatization, commercialization, or concession. Zhang et al. (2018) conducted a comprehensive literature review to address the fundamental issues of port governance and highlight the emergence of multilevel governance, the increased involvement of national and regional governments in some countries, and the predominance of local port authorities in managing port operations.

Furthermore, some studies reveal the relationship between port competitiveness & performance and port privatization. Tongzon et al. (2005) conducted an empirical study of the effects of port privatization on the efficiency of port operation, and the result showed that private sector participation, to some extent, can improve port operation efficiency. Yuen et al. (2013) applied the DEA model to investigate how foreign and local ownership affects China`s container terminal efficiency, and the result shows that both foreign and local investment can improve port performance. Pagano et al. (2013) assessed port performance during government operation and private sector operations through financial econometric techniques. They provided an estimate of the savings and benefits of privatization. Besides, social welfare analysis on port privatization is also a popular topic. Matsushima et al. (2013) model the international hub port competition for transshipment traffic from third countries and found that the governments will privatize their ports to raise their national welfare, compared to the situation under public operation. Czerny et al. (2014) investigated the impacts of port privatizations on social welfare, where two ports located in different countries handle their own cargo and transshipment cargo, and the result provided additional support for the benefits of port privatization.

- **Motivation**

Overall, it is essential to make the decision between competition and cooperation (or co-opetition) in the dynamic shipping and port industry to maintain competitiveness. The adoption of different decisions will have direct and distinguishing implications for public and private interests. From the perspective of policymakers, it is desirable to have nearby ports performing similar services in overlapping hinterlands compete while those working together in the same maritime supply chain cooperate to maximize economic efficiency (Song, 2002; Álvarez-SanJaime et al., 2015). However, over-competition may result in a low-profit margin, which, in the long run, will damage the willingness of the port/carrier to continue investing. From a business point of view, cooperation and integration are highly preferred by the ports and carriers since they can raise their market power against other rivals or newcomers (Hoshino et al., 2010). And if the cooperation level is too high, the concern over low market efficiency will bring back more competition. Furthermore, the external policy will also add complexity to the existing relationship between ports and carriers. So, it is critical for the policy maker and various public/private participants to understand the dynamics and the relationships among competition and cooperation in the port and shipping industry, balancing private and public interests in challenging situations and obtaining competitiveness.

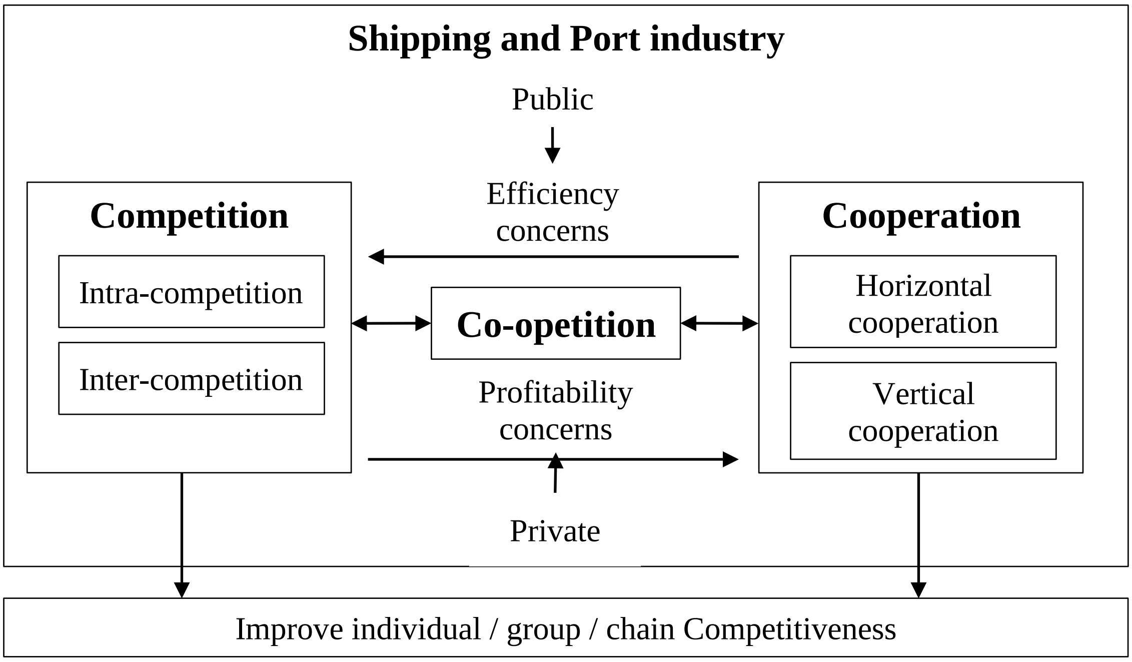

Figure 1 Competition, Cooperation, Public/Private, and Competitiveness

Source: Author

Perhaps the most important starting point of writing this thesis is that it can provide some tools to achieve a better understanding of the multidimensional nature of competitiveness (especially port competitiveness) by analyzing competition and cooperation among the carriers, ports, and other participants in the maritime transport chain. It is the author`s view that such an understanding can make a difference in at least maintaining or improving their competitiveness in the light of mainstream industry trends.

This PhD thesis aims to contribute to management literature by investigating competition and cooperation in the port and shipping industry based on several specific and linked topics. To analyze those cases, the studies develop, extend, or apply different methods/tools that can support the decision-making process for port authorities, port operators, carriers, and policy makers and reflect on their motivations and the logic behind them.

➢ Structure of the thesis

The thesis consists of five chapters that were referred to in the title as “essays,” which reflects the fact that each chapter can be considered separately and independently, although there are certain inter-related linkages among them. The sequence of chapters is presented in a logical way so that the earlier chapters can provide a certain rationale for the further development of the next chapter.

It is important to note that, at the outset of this thesis, instead of aiming to cover the whole topic of cooperation and competition in the shipping and port industry, this study concentrates on five related but individual studies, mainly in the "PORT" related area. Chapters 1 and 2 are mainly about cooperation: Chapter 1 is about vertical cooperation between shipping lines and railway operators in the port area, while Chapter 2 is about horizontal cooperation among shipping lines. Chapter 3 is about port competition and potential cooperation, and Chapter 4, on the other hand, is about vertical cooperation between a port (authority) and a shipping line. Chapter 5 is an extended port competition study regarding the effects of external greening policy. The thesis structure and the motivation/contribution of each chapter are in the following paragraphs. The author is aware of the fact that all these chapters do not contribute equally to scientific knowledge on the subject matter. ***Table 1*** summarizes the actors involved, the methodological focus, and the main ideas of each chapter.

Table 1 Thesis structure

Chapters	Actors involved	Methodological focus	Main idea in a nutshell
<u>Chapter 1:</u> An incentive approach in the collaboration between maritime and railway actors: A conceptual discussion	-Railway Operator -Shipping Line -Terminal Operator	-Conceptual discussion -Shapley Value	-Identification of the mismatching issue in the European ship-port-railway connection -Proposing a conceptual framework for an incentive mechanism to streamline this connection
<u>Chapter 2:</u> Horizontal collaboration among container shipping lines: voyage integration and benefit sharing	-Shipping Lines	-Voyage bundling with soft time windows -Shapley Value	-Estimating the total cost of possible coalitions, considering direct cost savings from voyage bundling and related penalty costs. -Application of Shapley Value to allocate the cost savings from voyage bundling
<u>Chapter 3:</u> A game theoretical approach to the effects of private objective orientation and service differentiation on port authorities' willingness to cooperate	-Port Authority (landlord port) -Private sector in landlord port -Private port	-Context of mixed duopoly/oligopoly -Four competing and cooperating scenarios -Social optimum and private optimum	-Comparing the payoffs between the cooperative and competing scenarios from the perspectives of Port Authority and Port Operator -Investigating the effects of port privatization and service differentiation on the difference in payoffs (to facilitate the potential cooperation/merger between the landlord port and private port)
<u>Chapter 4:</u> Vertical integration of shipping lines in port competition and expansion	-Shipping Line -Port Authority (Landlord port) -Terminal Operators -Private port	-Context of mixed duopoly/oligopoly -Different scenarios regarding the involvement of the shipping line in a new capacity expansion of the port	-Investigating the effects of the involvement of the shipping line in a new capacity expansion of the port by comparing the integration scenario and non-integration scenario
<u>Chapter 5:</u> Modelling emission control taxes in port areas and port privatization levels in port competition and co-operation sub-games	-Port Authority (Landlord port) -Private sector in landlord port -Private port -Government	-Context of mixed duopoly/oligopoly -Optimal emission control tax and privatization level in various competing and cooperative scenarios	-Calculating the optimal emission control tax/optimal privatization level in competing and cooperative scenarios -Comparing the payoffs of different actors in competing and cooperative scenarios

Chapter 1 "An incentive approach in the collaboration between maritime and railway actors: A conceptual discussion." The problem of conflicting interests within the port community, caused by bottleneck issues in maritime transport chains, is reviewed, and the related specific coordination problems in European port-railway connections are discussed. An incentive mechanism is introduced and applied based on the modified Shapley value method to help solve specific unpunctuality issues.

The contributions of this paper are as follows:

- Identification of the mismatching problem in European port-railway connections by revisiting the bottleneck issues in maritime transport chains
- Proposing a conceptual framework for an incentive mechanism, which can be used as a basis for collaboration in the maritime hinterland chains given enhancing mutual interactions.
- Application of the modified Shapley Value to allocate the benefits from the potential cooperation, which rewards the schedule-flexible partner mostly.
- From the *business point of view*, the incentive mechanism can serve as the basis for the logistic integration process, reducing the delay and making the maritime transport chain more efficient ("charge more for better service").

Chapter 2 " Horizontal collaboration among container shipping lines: voyage integration and benefit sharing." This paper revisits the advantages of a shipping alliance, with a specific focus on logistics collaboration, aiming at a lower cost with a fair arrangement. Hence, the paper further presents a framework for voyage integration/synchronization, together with the benefit-sharing from the perspectives of both individuals and group.

The contributions of this paper are as follows:

- A theoretical framework is developed to estimate the collaboration cost with the consideration of time-penalty cost and vessel laying-up cost.
- Application of Shapley Value to re-distribute the collaborative benefit among the participating carriers, trying to find a balance in view of satisfying all individual carriers while keeping a relatively low total cost. And proposing a basic solution to reduce the unfairness for the "negative gain" individual carrier by compensating in different ways.
- From the *business point of view*, voyage integration/bundling can be an effective strategy for raising capacity utilization, cutting costs, and re-distributing the profit, which could motivate the pro-active carrier to keep the viable coalition working. The framework can actively offer more competitive pricing, provide more flexible shipping options, and ultimately satisfy different customers.

Chapter 3 "A game theoretical approach to the effects of private objective orientation and service differentiation on port authorities' willingness to cooperate." By comparing the payoff differences between various competing statuses and cooperation statuses, this study provides a new perspective to understand the effects of service differentiation and port ownership structure in a mixed duopoly (where a private port is competing with a landlord port with differentiated service) and cooperation. Moreover, the chapter extends the results into the economic motivations of potential port cooperation schemes or mergers.

The contributions of this paper are as follows:

- Extending the mixed duopoly model to the competition between a landlord port and a private port, with consideration of differentiated service.
- Examining how the differentiated service and privatization will influence the various port competition scenarios and to what extent a potential port cooperation scenario can be achieved. Application of the theoretical result in the case of Shenzhen Port and Hongkong Port.
- For *policy makers*, especially for the port authority, with the current trend of port integration/cooperation, the results reveal that the type of competition, the service

differentiation, and privatization level will come together to play a vital role in the port authority`s willingness to merge, which needs to be carefully evaluated if the government is planning to integrate them.

Chapter 4 "Vertical integration of shipping lines in port competition and expansion." Based on an economic model, this paper attempts to investigate how vertical integration, in the form of the port`s new capacity expansion invested by shipping lines, in the context of a mixed duopoly (where a private port is competing with a landlord port, which is willing to invest new capacity either by itself or in combination with shipping line) affects individual actors, such as the port authority, port operator, the cooperative shipping lines, and its rival shipping lines. The contribution of this paper is to understand the economic motivation behind the integration of shipping lines and port from different perspectives. The results of the model suggest that a higher integration level can lead to higher port capacity, port charges, shipping line output, and social welfare, but it will weaken the competitiveness of other non-integrated shipping lines and rival port.

The contributions of this paper are as follows:

- Developing a mixed duopoly model in the context of new capacity investment, together with multiple competing shipping lines
- Examining the effect of integration on the integrated port and shipping line and on rival shipping lines and port as well
- For the *policy maker*, vertical integration is a trade-off question in that it raises the competitiveness of the integrated port and shipping line but undermines competition by damaging the profitability of rival port and shipping lines.

Chapter 5 "Modelling emission control taxes in port areas and port privatization levels in port competition and co-operation sub-games." With the greening of ports, it is crucial for the government and port authorities to understand the effect of setting a proper emission control tax scheme together with the procedure of privatizing the port in the current situation of fierce port competition and potential port cooperation. So, by modeling the interaction between emission control tax and port privatization in the context of port competition and cooperation, we found that the optimal private level of port 2 under Cournot and Bertrand competitions varies between fully private and highly public concerned ports, while the government will prefer a highly public concerned or close to the highly public concerned port in the cooperation scenario. Second, the government will have to make more and stricter efforts to enhance environmental protection in the situation of port cooperation (monopoly) than in the case of inter-port competition, and the optimal emission taxes should always be lower than the marginal emission damage. Third, port privatization has a non-monotonous effect on ports` environmental damage in the inter-port competition scenarios and a monotonous decreasing effect in the cooperation scenario. Fourth, the total emission tax revenue is always higher than the overall environmental damage in the cooperative scenario, and it may or may not be able to cover the whole environmental damage in Cournot and Bertrand competitions. Finally, the government may face a trade-off among environmental protection, maximizing social welfare, and satisfying individual motivation when considering port cooperation (monopoly).

The contributions of this paper are as follows:

- Developing a mixed duopoly model by introducing an emission tax in the context of port competition and further potential cooperation
- Examining the multidimensional impact of different factors, such as emission tax, port privatization level, and service differentiation, on environmental issues and social welfare in ports.

- For the *policymakers*, the government may partially privatize its ports in terms of maximizing social welfare, and the privatization level has various impacts on environmental damage in different competition and cooperation scenarios. Besides, the government needs to balance private and public interests and environmental protection.

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Slightly amended versions of Chapters 5 and 3 have been published in academic journals, respectively Transportation Research part D in 2017 and Research in Transportation Business and Management (RTBM) in 2018.

References

Álvarez-SanJaime, Ó., Cantos-Sanchez, P., Moner-Colonques, R. and Sempere-Monerris, J.J., 2015. The impact on port competition of the integration of port and inland transport services. *Transportation Research Part B: Methodological*, 80, pp.291-302.

Anderson, C.M., Park, Y.A., Chang, Y.T., Yang, C.H., Lee, T.W. and Luo, M., 2008. A game-theoretic analysis of competition among container port hubs: the case of Busan and Shanghai. *Maritime Policy & Management*, *35*(1), pp.5-26.

Aregall, M.G., Bergqvist, R. and Monios, J., 2018. A global review of the hinterland dimension of green port strategies. *Transportation Research Part D: Transport and Environment*, *59*, pp.23-34.

Bae, M.J., Chew, E.P., Lee, L.H. and Zhang, A., 2013. Container transshipment and port competition. *Maritime Policy & Management*, 40(5), pp.479-494.

Baltazar, R. and Brooks, M.R., 2006. Port governance, devolution and the matching framework: a configuration theory approach. *Research in transportation economics*, 17, pp.379-403

Benacchio, M., Ferrari, C. and Musso, E., 2007. The liner shipping industry and EU competition rules. *Transport Policy*, 14(1), pp.1-10.

Borger, B.D., Dunkerley, F. and Proost, S., 2008. The interaction between tolls and capacity investment in serial and parallel transport networks. *Review of Network Economics*, *7*(1).

Cariou, P. and Guillotreau, P., 2021. Capacity management by global shipping alliances: findings from a game experiment. *Maritime Economics & Logistics*, pp.1-26.

Cariou, P., 2008. Liner shipping strategies: an overview. *International Journal of Ocean Systems Management*, 1(1), pp.2-13.

Chang, Y.T. and Talley, W.K., 2019. Port competitiveness, efficiency, and supply chains: a literature review. *Transportation Journal*, *58*(1), pp.1-20.

Chen, J., Liu, X., Zhang, X., He, J. and Luo, L., 2017. Optimal bilateral cooperative slot allocation for two liner carriers under a co-chartering agreement. *The Journal of Navigation*, *70*(5), pp.1170-1182.

Chengjin, W., Ducruet, C. and Wei, W., 2015. Port integration in China: Temporal pathways, spatial patterns and dynamics. *Chinese Geographical Science*, 25(5), pp.612-628.

Crotti, D., Ferrari, C. and Tei, A., 2020. Merger waves and alliance stability in container shipping. *Maritime Economics & Logistics*, 22, pp.446-472.

Cullinane, K. and Khanna, M., 2000. Economies of scale in large containerships: optimal size and geographical implications. *Journal of transport geography*, 8(3), pp.181-195.

Cullinane, K. and Song, D.W., 2002. Port privatization policy and practice. *Transport Reviews*, 22(1), pp.55-75.

Cullinane, K., Song, D.W., Ji, P. and Wang, T.F., 2004. An application of DEA windows analysis to container port production efficiency. *Review of network Economics*, 3(2).

Cullinane, K., Teng, Y. and Wang, T.F., 2005. Port competition between Shanghai and Ningbo. *Maritime Policy & Management*, 32(4), pp.331-346.

Czerny, A., Höffler, F. and Mun, S.I., 2014. Hub port competition and welfare effects of strategic privatization. *Economics of Transportatio*n, 3(3), pp.211-220.

Das, S.S., 2011. To partner or to acquire? A longitudinal study of alliances in the shipping industry. *Maritime Policy & Management*, *38*(2), pp.111-128.

De Borger, B. and De Bruyne, D., 2011. Port activities, hinterland congestion, and optimal government policies the role of vertical integration in logistic operations. *Journal of Transport Economics and Policy (JTEP)*, *45*(2), pp.247-275.

De Langen, P.W. and Pallis, A.A., 2006. Analysis of the benefits intra-port competition. International Journal of Transport Economics, 33(1), p.69.

De Oliveira, G.F. and Cariou, P., 2015. The impact of competition on container port (in) efficiency. *Transportation Research Part A: Policy and Practice*, *78*, pp.124-133.

Dong, G., Zheng, S. and Lee, P.T.W., 2018. The effects of regional port integration: The case of Ningbo-Zhoushan Port. *Transportation Research Part E: Logistics and Transportation Review*, 120, pp.1-15.

Donselaar, P.W.V. and Kolkman, J., 2010. Societal costs and benefits of cooperation between port authorities. *Maritime Policy & Management*, 37(3), pp.271-284.

Fonseca, L.M., 2018, October. Industry 4.0 and the digital society: concepts, dimensions and envisioned benefits. In *Proceedings of the international conference on business excellence* (Vol. 12, No. 1, pp. 386-397).

Frémont, A. and Franc, P., 2010. Hinterland transportation in Europe: Combined transport versus road transport. *Journal of transport geography*, *18*(4), pp.548-556.

Frémont, A., 2009. Shipping lines and logistics. *Transport Reviews*, *29*(4), pp.537-554.

Ghorbani, M., Acciaro, M., Transchel, S. and Cariou, P., 2022. Strategic alliances in container shipping: A review of the literature and future research agenda. *Maritime Economics & Logistics*, pp.1-27.

Haralambides, H.E., Cariou, P. and Benacchio, M., 2002. Costs, benefits and pricing of dedicated container terminals. *International Journal of Maritime Economics*, 4(1), pp.21-34.

Hoshino, H., 2010. Competition and collaboration among container ports. *The Asian Journal of Shipping and Logistics*, 26(1), pp.31-47.

Hwang, C.C. and Chiang, C.H., 2010. Cooperation and competitiveness of intra-regional container ports. *Journal of the Eastern Asia Society for Transportation Studies*, *8*, pp.2283-2298.

Inoue, S., 2018. Realities and challenges of port alliance in Japan—Ports of Kobe and Osaka. *Research in Transportation Business & Management*, 26, pp.45-55.

Ishii, M., Lee, P.T.W., Tezuka, K. and Chang, Y.T., 2013. A game theoretical analysis of port competition. *Transportation Research Part E: Logistics and Transportation Review*, 49(1), pp.92-106.

Kaselimi, E.N., Notteboom, T.E. and De Borger, B., 2011. A game theoretical approach to competition between multi-user terminals: the impact of dedicated terminals. *Maritime Policy & Management*, 38(4), pp.395-414.

Kavirathna, C.A., Kawasaki, T. and Hanaoka, S., 2019. Intra-port coopetition under different combinations of terminal ownership. *Transportation Research Part E: Logistics and Transportation Review*, 128, pp.132-148.

Lee, E.S., 2019. Improving a firm's performance within a strategic shipping alliance. *The Asian Journal of Shipping and Logistics*, *35*(4), pp.213-219.

Li, J. and Jiang, B., 2014. Cooperation performance evaluation between seaport and dry port; case of Qingdao port and Xi'an port. *International Journal of e-Navigation and Maritime Economy*, 1, pp.99-109.

Liu, D., Deng, Z., Sun, Q., Wang, Y. and Wang, Y., 2019. Design and freight corridor-fleet size choice in collaborative intermodal transportation network considering economies of scale. *Sustainability*, *11*(4), p.990.

Luo, M., Liu, L. and Gao, F., 2012. Post-entry container port capacity expansion. *Transportation Research Part B: Methodological*, 46(1), pp.120-138.

Matsushima, N. and Takauchi, K., 2014. Port privatization in an international oligopoly. *Transportation Research Part B: Methodological*, 67, pp.382-397.

Meng, Q. and Wang, S., 2012. Liner ship fleet deployment with week-dependent container shipment demand. *European Journal of Operational Research*, *222*(2), pp.241-252.

Monios, J. and Wilmsmeier, G., 2013. The role of intermodal transport in port regionalisation. *Transport Policy, 30*, pp.161-172.

Notteboom, T. and Yap, W.Y., 2012. Port competition and competitiveness. *The Blackwell companion to maritime economics*, pp.549-570.

Notteboom, T., Pallis, A., & Rodrigue, J. P., 2022. *Port economics, management and policy*. Routledge.

Notteboom, T.E. and Winkelmans, W., 2001. Structural changes in logistics: how will port authorities face the challenge?. *Maritime Policy & Management*, 28(1), pp.71-89.

Notteboom, T.E., 2010. Concentration and the formation of multi-port gateway regions in the European container port system: an update. *Journal of transport geography*, 18(4), pp.567-583.

Notteboom, T.E., Parola, F., Satta, G. and Pallis, A.A., 2017. The relationship between port choice and terminal involvement of alliance members in container shipping. *Journal of Transport Geography*, 64, pp.158-173.

Pagano, A.M., Wang, G.W., Sánchez, O.V. and Ungo, R., 2013. Impact of privatization on port efficiency and effectiveness: results from Panama and US ports. *Maritime Policy & Management*, 40(2), pp.100-115.

Panayides, P.M. and Wiedmer, R., 2011. Strategic alliances in container liner shipping. *Research in transportation Economics*, *32*(1), pp.25-38.

Paridaens, H. and Notteboom, T., 2022. Logistics integration strategies in container shipping: A multiple case-study on Maersk Line, MSC and CMA CGM. Research in Transportation Business & Management, 45, p.100868.

Parola, F., Risitano, M., Ferretti, M. and Panetti, E., 2017. The drivers of port competitiveness: a critical review. *Transport Reviews*, 37(1), pp.116-138.

Rau, P. and Spinler, S., 2017. Alliance formation in a cooperative container shipping game: Performance of a real options investment approach. *Transportation Research Part E: Logistics and Transportation Review*, *101*, pp.155-175.

Review of Maritime Transport 2022. UNCTAD, 29 Nov. 2022, https://unctad.org/publication/review-maritime-transport-2022.

Ryoo, D.K., 2011. A conceptual framework of port cooperation. *Journal of Navigation and Port Research*, 35(7), pp.581-588.

Saeed, N. and Larsen, O.I., 2010. An application of cooperative game among container terminals of one port. *European Journal of Operational Research*, 203(2), pp.393-403.

Sanchez-Gonzalez, P.L., Díaz-Gutiérrez, D., Leo, T.J. and Núñez-Rivas, L.R., 2019. Toward digitalization of maritime transport?. *Sensors*, *19*(4), p.926.

Shi, X., Ma, L. and Voß, S., 2020, July. On Designing a Slot Sharing E-Platform for Liner Shipping Services. In *International Conference on Human-Computer Interaction* (pp. 499-513). Cham: Springer International Publishing.

Slack, B., 1985. Containerization, inter-port competition, and port selection. *Maritime policy and management*, 12(4), pp.293-303.

Slack, B., 1993. Pawns in the game: ports in a global transportation system. *Growth and change*, 24(4), pp.579-588.

Slack, B., Comtois, C. and McCalla, R., 2002. Strategic alliances in the container shipping industry: a global perspective. *Maritime Policy & Management*, 29(1), pp.65-76.

Song, D. W., 2003. Port co-opetition in concept and practice. *Maritime Policy & Management*, 30(1), 29-44.

Song, D.P., Lyons, A., Li, D. and Sharifi, H., 2016. Modeling port competition from a transport chain perspective. *Transportation Research Part E: Logistics and Transportation Review*, 87, pp.75-96.

Song, D.W. and Panayides, P.M., 2008. Global supply chain and port/terminal: integration and competitiveness. *Maritime Policy & Management*, 35(1), pp.73-87.

Song, D.W., 2002. Regional container port competition and co-operation: the case of Hong Kong and South China. *Journal of Transport Geography*, 10(2), pp.99-110.

Soppé, M., Parola, F. and Frémont, A., 2009. Emerging inter-industry partnerships between shipping lines and stevedores: from rivalry to cooperation? Journal of *Transport Geography*, 17(1), pp.10-20.

Sugawara, J., 2017. Port and hinterland network: a case study of the Crescent Corridor intermodal freight program in the US. *Transportation Research Procedia*, *25*, pp.916-927.

Tan, Z., Meng, Q., Wang, F. and Kuang, H.B., 2018. Strategic integration of the inland port and shipping service for the ocean carrier. *Transportation Research Part E: Logistics and Transportation Review*, *110*, pp.90-109.

Tian, X., Liu, L. and Wang, S., 2015. Evolving competition between Hong Kong and Shenzhen ports. *Maritime Policy & Management*, *42*(8), pp.729-745.

Tongzon, J. and Heng, W., 2005. Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals*). Transportation Research Part A: Policy and Practice,* 39(5), pp.405-424.

Wang, C., Ducruet, C. and Wang, W., 2015. Port integration in China: Temporal pathways, spatial patterns and dynamics. *Chinese Geographical Science*, *25*, pp.612-628.

Wang, K. and Zhang, A., 2018. Climate change, natural disasters and adaptation investments: Inter-and intra-port competition and cooperation. *Transportation Research Part B: Methodological*, 117, pp.158-189.

Wang, K., Ng, A.K., Lam, J.S.L. and Fu, X., 2012. Cooperation or competition? Factors and conditions affecting regional port governance in South China. *Maritime Economics & Logistics*, 14, pp.386-408.

Wang, W., Xu, X., Jiang, Y., Xu, Y., Cao, Z. and Liu, S., 2020. Integrated scheduling of intermodal transportation with seaborne arrival uncertainty and carbon emission. *Transportation Research Part D: Transport and Environment*, *88*, p.102571.

Wu, S. and Yang, Z., 2018. Analysis of the case of port co-operation and integration in Liaoning (China). *Research in transportation business & management*, 26, pp.18-25.

Yap, W.Y., Lam, J.S. and Notteboom, T., 2006. Developments in container port competition in East Asia. *Transport Reviews*, *26*(2), pp.167-188.

Yip, T.L., Liu, J.J., Fu, X. and Feng, J., 2014. Modeling the effects of competition on seaport terminal awarding. *Transport Policy*, 35, pp.341-349.

Yuen, A.C.L., Zhang, A. and Cheung, W., 2013. Foreign participation and competition: A way to improve the container port efficiency in China? *Transportation Research Part A: Policy and Practice*, 49, pp.220-231.

Zhang, Q., Geerlings, H., El Makhloufi, A. and Chen, S., 2018. Who governs and what is governed in port governance: A review study. *Transport Policy*, 64, pp.51-60.

Zhang, R., Jian, W. and Tavasszy, L., 2018. Estimation of network level benefits of reliability improvements in intermodal freight transport. *Research in Transportation Economics*, *70*, pp.1-8.

Zheng, J., Gao, Z., Yang, D. and Sun, Z., 2015. Network design and capacity exchange for liner alliances with fixed and variable container demands. *Transportation Science*, *49*(4), pp.886-899.

Zhou, X., 2015. Competition or cooperation: a simulation of the price strategy of ports. *International Journal of Simulation Modelling*, *14*(3), pp.463-474.

Zhu, S., Zheng, S., Ge, Y.E., Fu, X., Sampaio, B. and Jiang, C., 2019. Vertical integration and its implications to port expansion. *Maritime Policy & Management*, *46*(8), pp.920-938.

Zhuang, W., Luo, M. and Fu, X., 2014. A game theory analysis of port specialization—implications to the Chinese port industry. *Maritime Policy & Management*, *41(3), pp.268-287.*

Zondag, B., Bucci, P., Gützkow, P. and de Jong, G., 2010. Port competition modeling including maritime, port, and hinterland characteristics. *Maritime Policy & Management*, *37*(3), pp.179-194.

Chapter 1 An incentive approach in the collaboration between maritime and railway actors: A conceptual discussion

Abstract

The integration of different actors into maritime supply chains becomes more and more critical. However, with the rising degree of integration, coordination problems are emerging between actors in the port community due to the intensification of conflicting interests. Specifically, reliability and punctuality issues are particularly problematic in the case of the deep-sea terminal-railway connection in seaports. Any unexpected delay in ship or train arrival will be gradually amplified in the entire transport chain. A proper incentive mechanism might help to overcome these obstacles and motivate every partner to collaborate better. This paper presents a conceptual framework to contribute to research on vertical collaboration in maritime port-hinterland transport chains.

First, by presenting the bottleneck issues in maritime transport chains, we outline the conflicts of interest within the port community. Then, an incentive mechanism is introduced to reduce these negative effects by relaxing the chain-controlling power.

Second, the specific coordination problem in European port-railway connections is highlighted. Then, based on the basic principle of the first section, we apply a modified Shapley Value method to solve the specific issues related to a lack of punctuality. We show that the profit/cost allocation method will especially reward the schedule-adapting action so that the actor will be motivated to relax their constraints to match each other in view of reducing the effect of delays.

Keywords: *maritime-railway transport, Collaboration, Schedule adapting, Shapley Value, Game theory*

1.1 Introduction

Since the 1980s, the growth rates of global container ports have consistently been between 5% and 10%, largely due to the widespread adoption of large-scale containers and the process of globalization. Throughput grew from 36 million TEU in 1980 to 237 million TEU in 2000, 545 million TEU in 2010, more than 740 million TEU in 2017, and 802 million TEU in 2019, just before the Covid-19 pandemic (Theo Notteboom et al., 2022).

Growing container volumes have increased the demand for coordination among shipping lines, terminals, and inland transport operators, representing the major actors in the maritime transport chain. Such coordination is needed to satisfy the increasing logistics requirements in terms of logistics costs, reliability, flexibility, etc. For instance, the growing scale asymmetry between marine vessels (with a unit capacity from 7,000 to 24,000 TEU) on the one side and trains (40-90 TEU), barges (30-500 TEU), and trucks (max 2 TEU) on the other, is putting economic and operational pressure on the (competitive and/or collaborative) relationships among carriers, stevedores, etc. Moving a container from the origin to the destination requires many operational coordination decisions to be taken and includes several moments of handover of the container from one player to the next (Fransoo and Lee, 2012). If any actor is not well integrated into the logistics flow, additional costs, unnecessary delays, and accidents may arise, distorting the smooth flow of goods (Lee et al., 2012). Competition among individual actors shifted to the corresponding chain competition since customers are now particularly concerned about the overall channel fluency and efficiency instead of the performance of each of the segments in the chain. Specifically, Robinson (2002), Bichou (2006), Tongzon (2009), Song et al. (2008), and Panayides et al. (2009) all emphasize the importance of supply chain integration, mainly by illustrating its effects on port or chain performance. Dias et al. (2010) investigate the role of ro-ro terminals in automotive supply chains, thereby adjusting the traditional concepts and terminology on integration. De Borger et al. (2011) examined the vertical integration between terminal operators and inland transporters and found that vertical integration will have a different impact on optimal port charges and congestion fees in terms of welfare, and that integration by the government will be beneficial in the logistic chain. Álvarez et al. (2015) studied the port integration with inland transport under inter-port competition and found that under certain circumstances, the port benefits from the integration but at the cost of certain shippers.

The collaboration and integration between ocean carriers and terminals/ports on the foreland side has developed well over the past decades, helped by the corporatization and privatization of ports and the rise of dedicated container terminals at strategic locations in the global shipping network. By doing so, it can help shipping lines reduce their risk (Notteboom et al., 2012) and help the port authority to obtain more investment to accommodate more traffic volume, infrastructure requirements, and financial risks (Notteboom et al., 2009; Psaraftis et al., 2012). Notteboom et al. (2017) examined how the involvement of shipping lines in container terminals affects port selection in the inter-continental liner service network. The result showed that ports would have a much higher chance of receiving calls of an alliance when the members were stakeholders of the port terminals, which is consistent with the perceived point that vertical integration can improve port competitiveness. Meanwhile, from the regulation perspective, Van De Voorde et al. (2010) suggested that vertical integration presents a constant challenge to the regulating authorities. Riordan (2008) mentioned that "antitrust policy in the United States recognizes that a vertical merger can create incentives for anticompetitive foreclosure or facilitate collusion while remaining mindful that vertical integration can achieve efficiencies."

However, the overall chain performance relies not only on the quality of the sea-leg segment but also on that of the landside segment. De Langen (2004; 2008) argued that hinterland access is now perceived as a key success factor for European ports. Providing hinterland accessibility, to a large extent, is a coordination challenge. The organizational and operational efficiency of port-related hinterland connections in terms of available infrastructure and the provision of efficient inland transport services form key determinants in the competition among ports (De Langen, 2007; Tongzon, 2009). The quality of efficient hinterland connections is the result of the joint action by a set of actors with a great deal of operational interdependence. These interdependent activities between two or more actors need to be managed (Malone and Crowston, 1994). As a result, a proper coordination mechanism among the actors, who often have conflicting interests, is needed to guarantee fluent and efficient hinterland accessibility. Only a few studies have paid attention to the coordination issues in container hinterland transport, particularly when it concerns maritime-railway chains in a liberalized European rail market (Van Der Horst and Van Der Lugt, 2014). Ge et al. (2020) concluded that lack of institutional design/system regulation, insufficient cooperation and investment, and, most importantly, incentive policies rather than direct subsidies are the main problems in the Chinese Port Sea-rail intermodal transport policy. From the perspective of the port authority, Baccelli et al. (2020) evaluated the policies and strategies for promoting inter-modal transportation between Italian ports and inland regions, particularly by shifting transportation from road to rail, and the results show the critical role of the Port Authority in accelerating that process. The terminal-rail segment of hinterland transport chains is particularly vulnerable to disruptions (Woodburn, 2019) as the schedules on both sides (i.e., ships and trains) are not matching very well because of a lack of contractual relationships. This makes this segment vulnerable to specific challenges, including vessel schedule unreliability, rigid shuttle train schedules, and long timetabling processes.

This paper presents a conceptual framework in order to contribute to research on vertical collaboration in maritime port-hinterland transport chains. The paper is structured as follows: in the first section, by presenting the bottleneck issues in the port community, we outline the conflicts of interest among different major actors in the maritime-hinterland transport chains. Then, a theoretical incentive mechanism is proposed to reduce these negative effects of conflicting interests by compensating the actor who gives up certain chain-controlling power, and finally, to enhance the collaboration and improve chain performance. In the second section, the specific coordination problems at the level of the railway sector and shipping lines in Europe are illustrated. Then, we apply a modified Shapley Value method to solve the specific unpunctuality issues based on the basic principle presented in the first section. We show that the profit/cost allocation method should not only divide the profit/cost fairly but should also reward schedule adapting actions so that the actors will be motivated to relax their constraints to match each other in view of achieving a better chain performance.

1.2 The principle of “trading chain-controlling power by compensation”

This section focuses on the primary incentive/cooperative mechanism in view of introducing the principle of the incentive approach in port-related collaboration. We start with discussing the hazard problem/bottleneck issues in port-related transport chains. Conflicting interests of different actors’ compromise collaboration. Then, we introduce a basic incentive framework based on the basic idea that the actor who gives up certain chain-controlling powers (the power of making decisions) to another actor to enhance mutual collaboration should be compensated for his sacrifice by the other actor.

1.2.1 Bottleneck issues and conflicting interests

The globalization of the world economies and the dynamics of manufacturing and distribution have created intensive pressure on port-related supply chains in terms of reliability, responsiveness, flexibility, cost, and efficiency (Shepherd and Gunter, 2011). Bottlenecks manifested by those intensive pressure in the transport chain can emerge and persist due to a variety of factors, e.g., limited terminal capacity, poor planning and coordination, unreliability of vessel schedule, labor disputes/strikes, regulatory and security measures, and natural disasters and pandemics. ***Figure 2*** shows how container shipping schedule reliability (i.e., the share of container vessels arriving on the date shown in the published liner service schedules) changed over the past five years, highlighting the extremely low schedule reliability in 2021/2022 during the pandemic-induced global supply chain crisis (Notteboom et al., 2021; Cullinane et al., 2023). On the other hand, the schedule reliability and accurate application of Just in Time (JIT) and Just in Sequence (JIS) are substantial advantages that can be gained from locomotives (Freightera, 2019) in port.

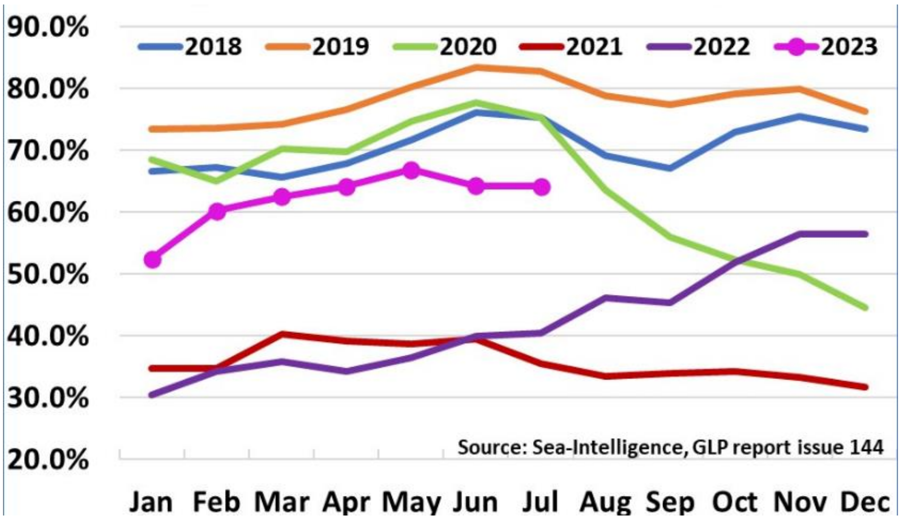

Figure 2 Global schedule reliability in container shipping

Source: SeaIntellgence

Existing port literature underlines the importance of providing smooth and efficient hinterland accessibility and the resulting **coordination challenges** linked to the operational interdependence between the actors (Van Der Horst and De Langen, 2008). Indeed, ports as nodes in transport chains are potential sources of cost-incurring chain disruptions resulting from long dwell/transit times and a general lack of synchronization. For example, Australian case studies on the coal-exporting ports of Newcastle and Dalrymple Bay (Lloyd’s List DCN, 2007 and Robinson, 2007) reveal that a vast imbalance between terminal handling capacity and cargo volume resulted in queues of dozens of dry bulkers, sometimes waiting for two months before being called in port for loading coal. At first glance, these delays were caused by insufficient infrastructure capacity, low productivity, and low coordination between ports and other actors. However, it was revealed that the actors were all following an isolated/segmented “leaning” strategy, maximizing their own profits/efficiency in the specific situation and, at the same time, compromising chain performance partly because of a lack of collaborations. Another case study in Sub-Saharan African ports (World Bank, 2012) also reveals a similar problem that most delays in the SSA ports are due to transaction and storage time, resulting from competition between shipper, consignee, port, and controlling agency. Rodrigue and Notteboom (2009) also argued, from the logistics provider`s perspective, that “delay” in ports may result from the deliberate intentions to save certain warehousing costs.

Different actors are attempting to achieve their own strategic objectives (maximizing their own profit). The interaction of different conflicting strategies can result in a more complex situation in port-related transport chains, causing bottleneck problems and putting more pressure on coordination. The self-centered focus of actors and the associated inertia in the chain can be caused by several factors as below:

First, if port congestion occurs, terminal operators may be reluctant to take immediate action because of the high utilization/profits of port facilities in a congestion situation, like a high berth occupancy, a high utilization rate of cranes/yard area (which is not favored by the shipping companies and consignees) and even the possibility to set higher terminal handling fees given the demand/supply imbalance.

Second, in case the vessel is delayed, the shipping company or shipowner does not necessarily end up incurring losses. In tramp shipping, demurrage fees should cover the costs of ships waiting to enter the port. In liner shipping, container carriers can impose congestion surcharges on their customers (on top of the freight rate) to compensate for waiting times in highly congested ports. Also, Notteboom (2006) demonstrated that shipping companies are not so eager to speed up or cut certain ports of calls to maintain schedule reliability as these actions might lead to higher operational costs.

Third, if the inland carrier cannot pick up the cargo in port due to the late arrival of a vessel, they cannot always or will divert from their own scheduled timetable because of the higher costs it brings and other infrastructural or operational constraints. This is particularly the case for scheduled mass transport modes such as container trains and container barges.

Aside from qualitative analysis of bottleneck issues in port-related transport chains, measuring bottlenecks is also a critical step to improve overall chain performance. In general, the method of measuring bottlenecks can be determined by the type of bottleneck, which can be categorized into physical and institutional (Down and Leschine, 1990), where a physical bottleneck mainly refers to infrastructure issues and operational decisions, and the institutional bottleneck is related to managerial issues, including information sharing and contractual commitments, etc. For instance, the managerial bottleneck can be identified and measured by Multiple Criteria Decision Analysis (MCDA) based on the inputs of expert systems or surveys. On the other hand, the operational-level bottleneck can be measured by monitoring KPIs, including the capacity utilization method (Hoshino et al., 2007; Kulak et al., 2013), queue length and waiting time method (Kiani Moghadam et al., 2010), Sensitivity analysis method (Demirci, 2003; Boschian et al., 2011), average active duration method (Roser et al., 2001), etc.

1.2.2 The basic cooperative framework and the generalized Stackelberg model

As mentioned earlier, the individual optimization (profit-maximizing) that each actor is attempting to achieve creates considerable complexity and bottleneck issues, compromising the whole performance of the (port) supply chain. To overcome the hazard of individual optimization, certain methods of coordination are presented. Van Der Horst and Van Der Horst and De Langen (2008) argued that there are four coordination mechanisms for port-related collaborations, including introducing incentives, creating an inter-firm alliance, changing scope, and creating collective action. Still, we believe the core mechanism still relies on the incentive mechanism or the proper profit/cost allocation mechanism. The framework we present is based on the incentive mechanism, that if the actor follows the strategy of the other actor by showing certain flexibility, the other actor should compensate for the sacrifices of the followers. In other words, the actor who is less flexible/elastic, or in other words, has more rigid operational constraints (compared with its partner) will tend to control its partner's pattern to make the whole channel adapt to its rigid pattern. The other actor, who is more flexible/elastic and adapts to its partner's solution, has to be compensated for its sacrifice. By implementing such a solution, both the payoffs of the individual actors as well as the entire chain will be improved.

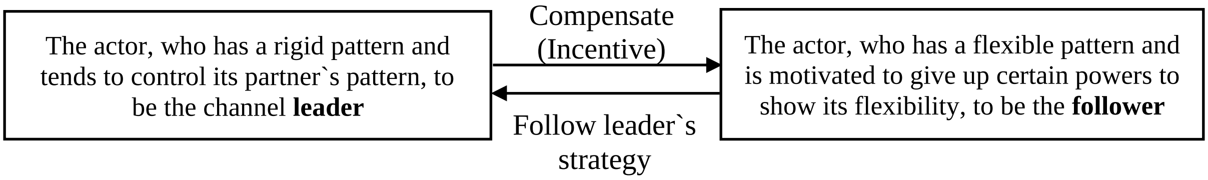

Figure 3 The basic principle of the incentive mechanism

Source: adapted from Van Der Horst and De Langen (2008)

In order to further underpin the motivation for introducing such an incentive mechanism, we compare the status of "stand-alone" (or we can say individual optimization-Nash equilibrium) with the status of "collaborated" (collaboration and rewarding-modified Stackelberg competition). In the status of "stand-alone," the individual optimization perfectly fits the Nash equilibrium. Each rational actor is carrying out their self-benefiting strategies to maximize their own payoffs, regardless of the strategies of other actors. Moreover, no actor can gain more by changing its own strategy. In such a situation, there is no positive/active collaboration between actors. In contrast, the status of "collaboration" could be expressed in the form of a modified Stackelberg Model in which the follower will obey the strategy of the leader and will receive compensation for this obedience (i.e., an incentive). Under these circumstances, the leader, together with the follower, will work harder to achieve not only better individual payoffs but also a better overall payoff.

To apply the incentive mechanism to maritime-related supply chains, we only consider two actors: maritime-related actor 1 and maritime-related actor 2 (we hypothetically consider them as shipping lines and hinterland carriers). The calculation is adapted from Wang et al. (2006), which can be found in the appendix.

To figure out the effect of the basic mechanism, the two different situations are compared: the status of "Nash equilibrium" (each actor is trying to maximize its own payoffs) and the status of "working together" by forming a sequential order through compensation.

Based on the result of the comparison between the Nash equilibrium and the modified Stackelberg model, the incentive mechanism has the potential to guarantee the rationale for the overall chains and individual actors by enhancing the collaboration by trading the chain-controlling power. In other words, by relaxing the constraints of one actor to follow another actor`s strategy (i.e., showing its flexibility and compensating for its sacrifice), the whole group and individual actors both can gain higher payoffs, compared with the status of "conflicting interests in the Nash Equilibrium."

As the port is naturally acting as the buffer/intermodal area where cargo is interchanged, port operators are typically called upon to be the most flexible actor in the chain. So, they are often urged to adapt to or follow more rigid actors in the chain, such as shipping lines and hinterland carriers. Specifically, in the shipping line-port-railway transport chains, the port operator can choose to adapt to the pattern of a shipping line or to that of the railway sector. In the remainder of the paper, we do not consider terminal operators as separate actors in the chain but only consider two actor sides: the maritime side (shipping line) and the inland operator side (in our case, rail). By doing so, the three-partner game will be simplified into a two-partner game. In the next section, we apply this basic principle to this chain to reward the collaborative measures of schedule adaptation between a shipping line and a railway actor in the port context.

1.3 A conceptual discussion of the application of incentive mechanisms to the maritime-rail connection in Europe

Maritime-hinterland transport services have become increasingly important due to the extension of potential hinterlands and the massive volumes being handled in seaports. The advantages of high transport efficiency and sustainability stimulate the use of rail on hinterland corridors.

1.3.1 The coordination problem in the maritime-railway connection

As we mentioned above, the interdependence of each actor, or the coordination problem, is putting a lot of pressure on hinterland transport chains. Specifically, in the maritime-rail connection, a combination of rigid rail shuttle schedules and the unreliability in vessel arrival patterns gives rise to disruptions and coordination problems in port-hinterland transport chains. In other words, if the schedules of ships and trains do not match for unexpected reasons, e.g., a delay of a vessel or train shuttle, more delays may happen in the subsequent transport chains due to this interruption.

➢ **The railway side**

The European liberalization of railways began with the unbundling of the railway infrastructure and railway operations and then shifted to the removal of railway entry barriers for each country. The rail infrastructure is managed by mostly national rail infrastructure managers, who coordinate the allocation of international train paths and tariff settings through RailNetEurope (RNE). The other two key actors in the rail sector are the railway operators and the railway companies. The railway operators will organize the train shuttles, mostly without owning the locomotives and wagons. The railway companies make locomotives and wagons available to railway operators, but they still need to apply for train paths allocated by infrastructure managers. The infrastructure managers allocate the railway capacity to all the applicants to maintain a high utilization rate of the tracks and preferably a good spread of traffic during the day. In case of railway capacity constraints on certain corridors, the infrastructure manager will not be able to meet all requests for train paths. Also, last-minute changes to train paths requested by an operator will be challenging to implement in case of a highly used rail infrastructure (even if the change would only be requested for one train).

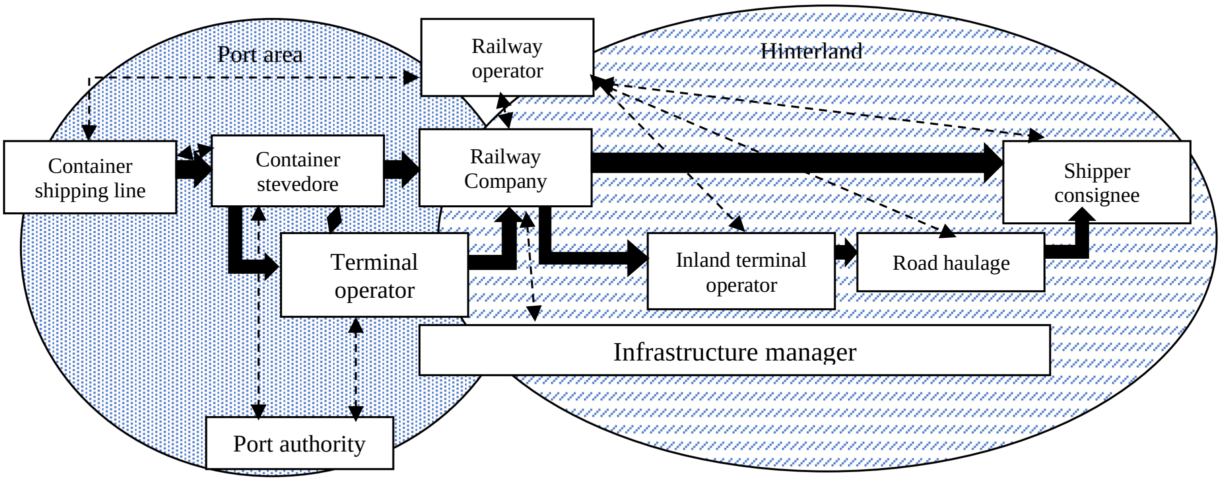

Figure 4 Intermodal railway chains

Source: Van Der Horst and de Langen (2008)

The increasingly complex relationship between infrastructure managers and other rail actors and the step-by-step and often lengthy procedure to obtain train paths compromise internal and external coordination. As there are mostly no contractual relationships between the railway sector and the port and shipping lines, coordination might prove difficult to achieve in practice. Van Der Horst and de Langen (2008) argued that a daily terminal-handling plan with a time slot for each train on the terminal, aiming at maximizing chain efficiency, may fall short due to the lack of contractual arrangements between the railway actor and the port. So, in essence, railway liberalization has made the potential for flexibility on the railway side more complex.

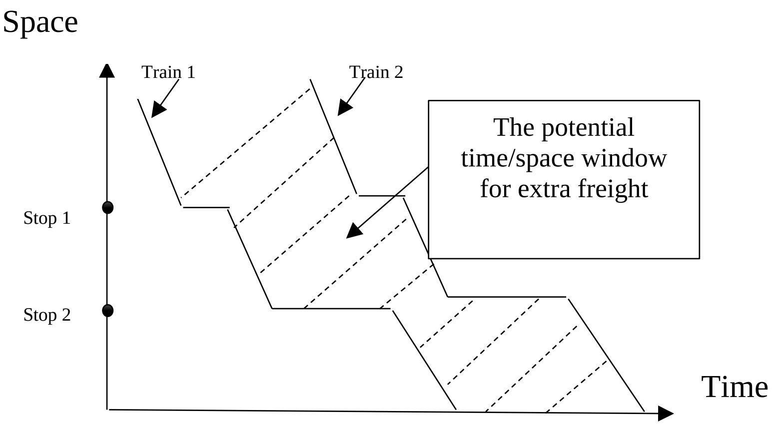

Figure 5 Rail service flexibility

Source: Adapted from Morvant (2014)

Some European countries have made changes by implementing a more flexible scheduling approach, e.g., France launched a timetable planning which allows the path orders from September of the last year until seven days before the train movements (Morvant, 2014). However, many corridors are facing full train path schedules, partly because of the mix of passenger and freight trains, particularly during the day. So, in practice, infrastructure managers cannot show a lot of flexibility in terms of changing train paths allocated earlier. In other words, the fuller the timetable, the harder it is to be flexible (e.g., by inserting an extra train or by moving existing train paths to a later day in the week) or, depending on the pricing methods of the railway infrastructure manager, the more expensive flexibility becomes. In Figure 3, the available time/space window depends on the density of already scheduled trains. Dedicated freight railways might offer more flexibility as interference with (often faster) commuter passenger trains can be avoided. For now, the number of dedicated freight tracks in Europe remains limited. The Betuweroute in the Netherlands, linking the port of Rotterdam to the German hinterland, is a notable example.

➢ The vessel and port side

A major threat to the future of complex liner service networks lies in increased schedule unreliability. Low schedule integrities can have many causes, ranging from weather conditions and delays in the access to ports (pilotage, towage, locks, tides) to port terminal congestion or even security considerations. Notteboom (2006) demonstrated that port terminal congestion is often the main cause of schedule unreliability. Given the nature of many liner services (more than one port of call, weekly service, hub-and-spoke configurations, etc.) that are closely integrated, delays in one port cascade throughout the whole liner service and, therefore, also affect other ports of call (even those ports that initially had no delays). The low schedule integrity is a serious challenge for terminal managers as their planning tools can only work optimally when the ship arrivals can be forecasted rather accurately (based on allocated slots).

There are several measures shipping can take to fight schedule integrity problems, but all these solutions imply additional operating costs (Notteboom, 2006):

- Shipping lines could add time buffers to the sailing schedule of the vessels. However, this might imply that the shipping line must insert an additional ship in the liner service so that a weekly call in each port of call can remain guaranteed.
- Shipping lines could make ad hoc changes to the order of port calls. However, this will leave some customers better off than others. In essence, you shift the problem from one port to another.
- A shipping line can skip one or more ports of call during a round voyage to save time. Such a decision leads to additional costs for the shipping lines as they will have to pay for the inland transport costs to the scheduled but skipped port of call.
- Shipping lines can speed up their vessels to make up lost time. However, most shipping lines are quite reluctant to do so as bunker costs are much higher than a decade ago, and bunker consumption goes up exponentially with vessel speed (Notteboom and Vernimmen, 2009).

It is expected that the issue of schedule unreliability will become even more critical in the future as liner service networks become more complex, ships are getting larger, container volumes surge, and new terminal capacities in some parts of the world do not come on stream in time. Under such circumstances, guaranteeing high schedule reliability and a high transit time reliability to global supply chains will have an ever-higher price, and this could have an impact on supply chain efficiency.

Vessel delays compound to delays in inland freight distribution. The potential operational effects of vessel delays and a lack of synchronization are getting more problematic as container vessel sizes and call sizes increase. Large vessels lead to peaks in the terminal activity. Late arrival of such a mega vessel implies all transport modes (truck, rail, barge) will be affected. First, the scheduled services are not able to load all the import cargo they were supposed to pick up at the terminal. This implies that some of the import cargo will have to be picked up by later barge and rail services, leading to (1) longer dwell times on the terminal, which negatively affects terminal capacity, and (2) imbalances and peaks in the utilization of consecutive inland shuttles. Second, the export containers discharged in the port will face longer dwell times at the terminal before they can be loaded onto the ship. The barge and rail operators could consider adjusting their schedules to the new arrival times of the vessels, but as we discussed earlier, this is not easy given all kinds of operational and infrastructural considerations.

The port/terminal, acting as the buffer area between the shipping line and the railway sector, has to invest much more in the corresponding infrastructure and facilities to reduce the specific congestion and improve productivity in order to be ready for flexibility.

In addition, the formal responsibilities and ownership of the various actors in bottleneck issues can influence the actors' priorities, decision-making, and ability to address and mitigate bottlenecks. Public ownership often emphasizes public interest and regulatory compliance, while private ownership emphasizes efficiency and productivity.

Table 2 The role of private/public actors in bottleneck issues

Actor	**Ownership**	**Role in the bottleneck**
Railway company /operator	Private or public entities	-Arranging the cargo transportation by rail -Focus on efficiency and schedule reliability
Infrastructure manager	Public entities	-Coordinating allocation of rail paths, setting tariffs -Focusing on railway overall schedule reliability, capacity utilization, and safety
Inland terminal operator	Private or public entities	-Facilitating the intermodal transshipment -Focus on efficiency and schedule reliability
Terminal operator	Private entities	-Managing cargo transfer/storage/logistics -Focus on efficiency and productivity
Port Authority	Primarily public entities	-Monitoring port administration/development/management -Focus on capacity utilization and safety
Container shipping line	Primarily private entities	-Arranging cargo transportation by sea -Focus on efficiency and productivity

Source: Various resources

1.3.2. A hypothetical example on reliability issues

In the hypothetical example in Figure 4, a container vessel arrives in port each Monday, and the scheduled shuttle will deliver the arrived containers to the hinterland on the same day routinely. In this ideal situation, there will be no need for an incentive mechanism, and the dwell time of containers at the terminal can be kept at a strict minimum. Assume that the railway company and shipping line are working individually. If the vessel is delayed for some reason and will arrive at the port on Wednesday, then the shuttle cannot catch it and must take all the delayed containers the next Monday. In that situation, a two-day delay will be amplified into a one-week delay for the subsequent transport chains, and the dwell time at the terminal rises, thereby absorbing more of the yard capacity. However, if any side can adapt to the schedule of the other, a further reduction of subsequent delays could be achieved by such synchronization (if this reduction in delays can bring a positive marginal profit). In other words, in the hypothetical example, either the shuttle can re-schedule and match the late-arrived containers, or the vessel can speed up or skip certain ports of call to catch up to maintain schedule reliability. Both schedule-adapting measures could reduce the potential unpunctuality or improve schedule reliability, which, in return, should be rewarded if this reduction in delays can bring a positive marginal profit. Based on this hypothetical example, the power of making decisions on the schedules could be traded/synchronized by shifting certain profits as an incentive. The more flexible an actor is in adapting to the schedule of the other actor, the more compensation/profit gains should be awarded to motivate that actor.

As scheduled

	Vessel`s arrival	Shuttle`s delivery
Monday	▓	▓
Tuesday		
Wednesday		
Thursday		
Friday		

Deviated from Schedule

	Vessel`s arrival	Shuttle`s delivery
Monday	░	▓
Tuesday		
Wednesday	▓	░
Thursday		
Friday		

Figure 6 A hypothetical example on reliability issues in the vessel-rail interface

Table 3 The subsequent delays in different situations

	Both **stand-alone**	Shipping line/port **flexible** Railway **rigid**	Railway **flexible** Shipping line/port **rigid**
The consequence	One-week delay	No delay/schedule reliability maintained	2-day delay
The difference from the status “both stand-alone”	-	Schedule reliability kept	5-day delay reduced
The potential marginal income	-	Increased	Increased
The potential marginal cost	-	Increased	Increased
The potential marginal profit	-	Not sure	Not sure

*: Since schedule reliability is maintained/improved due to the schedule adaptation measures, there is potential room for extra freight charges.

**: As we analyzed above, all the measures to increase flexibility represent additional costs.

In Table 1, we demonstrate different scenarios for solving the delay issues. If both sides stand alone, the two-day delay will be amplified into a one-week delay due to the schedule of the next shuttle. If the shipping line can re-schedule to match the railway, there will be no delay for the following transport chain, thereby improving the schedule reliability and making potential room for additional freight charges. However, as we mentioned, re-scheduling the ships will be very costly, which will make the marginal profit unclear. The third scenario goes in a similar way, leaving the marginal profit unclear, too.

1.3.3. Conceptual discussion on the profit allocation method with schedule-adapting rewarding

To simplify the profit allocation, we propose two layers of profit allocation so as to reward the efforts of schedule adaptation towards a better transport chain service. In the first layer, the port/shipping line side will compete with the railway sector for a better profit allocation. Then, the second layer indicates how profit allocation can be further divided for each branch. In this paper, we only focus on the first layer of profit allocation between the port/shipping line and the railway sector.

The profit allocation mechanism works as follows. If the port/shipping line side shows flexibility by working together to adapt to the schedule of the railway sector (by speeding up vessels, skipping certain ports of call, or even accelerating cargo handling to shorten the vessel`s stay in the previous port), the profit allocated to port/shipping lines should be awarded based on the contribution of two individual actors in the second layer. On the other hand, if the railway sector relaxes its constraints to match the pattern of port/shipping lines, the three individual actors in the second layer will consecutively receive a bonus based on their marginal efforts. The railway operator will have to apply for an extra or change in train path to the infrastructure manager and change its rental arrangements for locomotives and wagons with the railway company. This paper will not go deeper into the second layer, as the modalities and costs of any changes are guided by a range of formal agreements and contracts between rail operators, railway companies, and infrastructure managers.

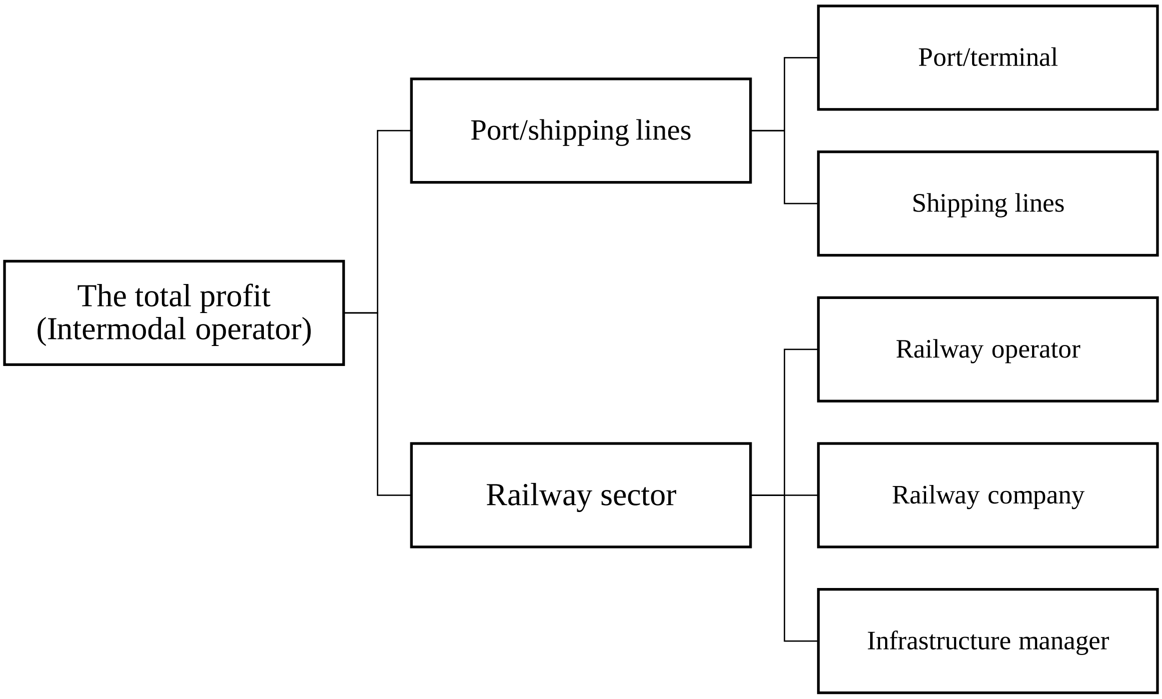

Figure 7 The profit allocation structure

Source: Authors

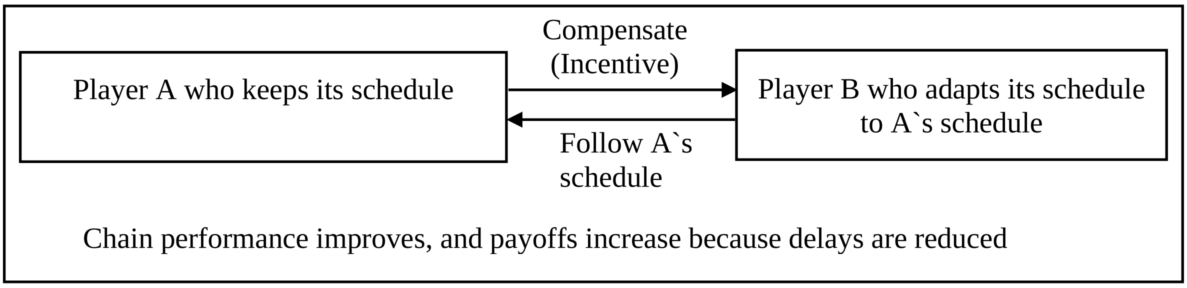

Figure 8 The principle of a schedule-adapting incentive

Source: Authors

Game theory approaches have been generally applied in the maritime context, mainly looking at port competition and maritime-related horizontal cooperation. However, little attention has been paid to the cost/profit/request/service/resource allocations in the maritime context, although this idea has been widely applied in horizontal collaboration in logistics to optimize transport operations. Bergantino and Coppenjans (1997) are probably the first authors to apply the cost allocation method (Shapley value) to divide the maritime joint costs. Furthermore, it seems there are even fewer studies to apply cost/profit allocation in maritime **vertical** collaboration. Álvarez-SanJaime et al. (2013) investigate the exclusivity of dedicated terminals following a game theory approach to vertical integration between shipping lines and terminals. Although this study does not discuss cost/profit allocation, it provides the conceptual fundaments to enhance maritime vertical collaboration from a game theory approach. Vanovermeire et al. (2014) raised the idea of measuring flexibility by comparing the cost status "before" and "after" horizontal logistics collaboration. They also applied multiple game theory approaches to allocate the cost in view of encouraging flexibility.

Although there are many methodologies for cost/profit allocation, few of them can be applied to vertical collaboration because of the problem of interpreting the individual/independent cost/profit. In other words, proportional allocation is suitable for horizontal cost/profit allocation rather than for vertical cost/profit allocation. In our case, we define the individual profit/cost, e.g., profit(a) and profit (b), as the profit when they are stand-alone. Finally, we opted for two vertically applicable approaches because of their characteristics, including Shapley value (Shapley, 1953) and Nucleolus (Schmeidler, 1969). The two approaches have different properties and characteristics: the Shapley value is solely based on the marginal contribution entering the coalition. The nucleolus emphasizes the minimization of the maximum unhappiness or the "average fairness".

In our case, the target is to award the marginal contribution (schedule-adaption measurement) in the given vertical system by shifting the balance of profit towards the more flexible partner as an incentive. So, based on that argument, the Shapley value should be the ideal methodology to measure that marginal contribution because of its properties and characteristics.

So, we introduce a profit (or cost applicable) allocation methodology based on the Shapley value and adapted from the cost allocation method of Vanovermeire (2014) to help solve schedule synchronization issues. The Shapley Value, based on the marginal contribution of one actor to all possible coalitions, can assign a unique distribution among players of a total cost generated by the coalition. This method can help to encourage an actor to release/relax its schedule constraints/rigidity, at least if this effort leads to a pay-off improvement, like a reduction of unpunctuality, profit increase, etc. The function of Shapley value consists of two basic parts: the weighted average and the marginal resulting from a withdrawal of player i.

$$Profit_i = \sum_{S \in N \setminus i} \frac{|S|!(|N|-|S|-1)!}{|N|!} \times [profit(S) - profit(S \setminus i)] \tag{1}$$

$profit_i$: the profit allocated to partner i
i: the partner i
S: (sub) coalition
N: the number of partners of the (sub) coalition
profit (S): the profit of coalition S
profit (S\i): The profit of coalition S if the coalition S removes partner i

However, the standard Shapley value cannot fairly divide the total profit in a **two-player** coalition as it always distributes the profit gains to both sides equally. The Shapley Value function in a two-player coalition gives the same results:

$$\begin{aligned} Allocated\ profit_P &= \frac{1}{2}(profit_{coalition} - profit_R) + \frac{1}{2}\left(profit_P - profit(\emptyset)\right) \\ &= profit_P - \frac{1}{2}(profit_{coalition} - profit_R - profit_P) \\ &= profit_P\ - \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{profit\ gains} \end{aligned}$$

$$Allocated\ profit_R = profit_R\ - \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{profit\ gains}. \tag{2}$$

But in the port/shipping line and railway sector case, the efforts of the two sides are contributing unequally to form the coalition. Although some researchers developed the weighted Shapley Value, which can correct the "equal" bias, defining the right weight is too subjective and hard to decide. So, to address the contribution of schedule adaptation, we hypothetically split the actor into two parts: flexible part and rigid part (Vanovermeire et al., 2014). This implies that for both actors, the profit of working alone (no schedule adaptation) will be considered as the profit of the rigid part. Including the flexible part when they form a coalition will help to identify the effect of the flexibility on the profit allocation. The flexible part does not exist on its own since the flexible part will never influence the coalition without involving its rigid part. Similarly, the profit of the flexible part will never affect the (sub) coalition alone without the company of the rigid part.

a_r: the rigid part of partner *a*
a_f: the flexible part of partner *a*
b_r: the rigid part of partner *b*
b_f: the flexible part of partner *b*

Table 1.2 provides an overview of the profit of all possible (sub) coalitions.

Table 4 The profit of all the (sub) coalitions

Profit(a_r)	Profit(a_r+a_f)	Profit(a_r+ b_f)=Profit(a_r)	Profit(a_r +b_r+ b_f)
Profit(a_f)=0	Profit(b_r+ b_f)	Profit(a_f+ b_r)=Profit(b_r)	Profit(a_f +b_r+ b_f)=Profit(b_r+ b_f)
Profit(b_r)	Profit(a_r+ b_r)	Profit(a_r+a_f+ b_r)	Profit(a_f + a_r +b_r+ b_f)
Profit(a_f)=0	Profit(a_f+ b_f)=0	Profit(a_r+a_f+ b_f)=Profit(a_r+a_f)	

Source: Adapted from Vanovermeire et al. (2014)

The new function of profit allocated to partner a in the two-actor coalition consists of two parts, which are calculated based on the Shapley value (adapted from the calculation of Vanovermeire et al., 2014):

$$\text{Profit}_{\text{a-new}}=\text{Profit}_{\text{a-rigid}}+\text{Profit}_{\text{a-flexible}} \qquad (3)$$

$$\text{Profit}_{\text{a-rigid}}=\frac{1}{4}\text{Profit}(\mathrm{a}_r)+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{a}_f)-\text{Profit}(\mathrm{a}_f)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{b}_r)-\text{Profit}(\mathrm{b}_r)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{b}_f)-\text{Profit}(\mathrm{b}_f)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{a}_f+\mathrm{b}_r)-\text{Profit}(\mathrm{a}_f+\mathrm{b}_r)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f)-\text{Profit}(b_r+\mathrm{b}_f)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+a_f+b_f)-\text{Profit}(\mathrm{a}_f+\mathrm{b}_f)]+\frac{1}{4}[\text{Profit}(\mathrm{a}_f+\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f)-\text{Profit}(\mathrm{a}_f+\mathrm{b}_r+\mathrm{b}_f)] \qquad (4)$$

$$\text{Profit}_{\text{a-flexible}}=\frac{1}{4}\text{Profit}(\mathrm{a}_f)+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{a}_f)-\text{Profit}(\mathrm{a}_r)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_f+b_r)-\text{Profit}(\mathrm{b}_r)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_f+\mathrm{b}_f)-\text{Profit}(\mathrm{b}_f)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{a}_f+\mathrm{b}_r)-\text{Profit}(\mathrm{a}_r+\mathrm{b}_r)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_f+\mathrm{b}_r+\mathrm{b}_f)-\text{Profit}(\mathrm{b}_r+\mathrm{b}_f)]+\frac{1}{12}[\text{Profit}(\mathrm{a}_r+\mathrm{a}_f+\mathrm{b}_f)-\text{Profit}(\mathrm{a}_r+\mathrm{b}_f)]+\frac{1}{4}[\text{Profit}(\mathrm{a}_f+\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f)-\text{Profit}(\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f)] \qquad (5)$$

After simplification:

$$\text{Profit}_{\text{a-new}}=\frac{1}{6}\text{Profit}(\mathrm{a}_r)+\frac{1}{3}\text{Profit}(\mathrm{a}_r+\mathrm{a}_f)-\frac{1}{6}\text{Profit}(\mathrm{b}_r)+\frac{1}{6}\text{Profit}(\mathrm{a}_r+\mathrm{a}_f+\mathrm{b}_r)-\frac{1}{6}\text{Profit}(\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f)-\frac{1}{3}\text{Profit}(\mathrm{b}_r+\mathrm{b}_f)+\frac{1}{2}\text{Profit}(\mathrm{a}_f+\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f) \qquad (6)$$

Similarly:

$$\text{Profit}_{\text{b-new}}=\frac{1}{6}\text{Profit}(\mathrm{b}_r)+\frac{1}{3}\text{Profit}(b_r+b_f)-\frac{1}{6}\text{Profit}(a_r)+\frac{1}{6}\text{Profit}(\mathrm{b}_r+b_f+\mathrm{a}_r)-\frac{1}{6}\text{Profit}(\mathrm{b}_r+\mathrm{a}_r+\mathrm{a}_f)-\frac{1}{3}\text{Profit}(\mathrm{a}_r+\mathrm{a}_f)+\frac{1}{2}\text{Profit}(\mathrm{b}_f+b_r+\mathrm{a}_r+\mathrm{a}_f) \qquad (7)$$

The new function will allocate more profit to partner a than in the standard Shapley value if the schedule-adaptation/profit gains resulting from the status of "**flexible *a*** and rigid *b*" is higher than the gains resulting from the status of "**rigid *a*** and flexible *b*". In other words, if the profit gained from flexible a is higher than the profit gained from flexible b, then partner a is the one that can show higher flexibility and thus should be rewarded or face profit increases. So, the partner who is able to be more flexible for generating higher schedule-adaptation/profit gains will be awarded more profits. This is proven below:

$$\text{Profit}_{\text{a-new}}-\mathbf{Profit_a}>0 \qquad (8)$$

$$\leftrightarrow\quad \frac{1}{6}\text{Profit}(\mathrm{a}_r)+\frac{1}{3}\text{Profit}(\mathrm{a}_r+\mathrm{a}_f)-\frac{1}{6}\text{Profit}(\mathrm{b}_r)+\frac{1}{6}\text{Profit}(\mathrm{a}_r+\mathrm{a}_f+\mathrm{b}_r)-\frac{1}{6}\text{Profit}(\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f)-\frac{1}{3}\text{Profit}(\mathrm{b}_r+\mathrm{b}_f)+\frac{1}{2}\text{Profit}(\mathrm{a}_f+\mathrm{a}_r+\mathrm{b}_r+\mathrm{b}_f)-\{\frac{\mathbf{1}}{\mathbf{2}}[\mathbf{profit}(\mathbf{a_f}+\mathbf{a_r}+\mathbf{b_r}+\mathbf{b_f})-\mathbf{profit}(\mathbf{b_r}+\mathbf{b_f})]+\frac{\mathbf{1}}{\mathbf{2}}[\mathbf{profit}(\mathbf{a_r}+\mathbf{a_f})-\mathbf{0}]\}<0$$

$$\leftrightarrow\quad [profit(a_r+a_f+b_r)]-profit(b_r)-profit(a_r+a_f)>[profit(a_r+b_f+b_r)]-profit(a_r)-profit(b_r+b_f)$$

However, since partner a is made up of two hypothetical statuses, the individual rationality (the profit allocated to the partner is always higher than the stand-alone cost), which is guaranteed by the standard Shapley value, will not be guaranteed by this approach. So, there may exist a biased encouragement of flexibility, so it is always necessary to check the individual rationality (e.g., the flexible actor is rewarded less than the rigid actor) before application to make sure the right flexibility is rewarded.

Besides, the parameter “profit” in all the formulas can be easily replaced by “cost” without changing the formula, so this approach can be applied in case of cost or profit allocations.

Since there is no standard assumption that the allocated profit is always higher than the stand-alone profit (i.e., the allocated cost is always lower than the stand-alone cost), there are three possible strategies for the actor based on the different actions of the other actor:

- Being scheduled –adapting in the coalition (the other one being rigid) - leading if the coalition and the individual rationality are satisfied.
- Being rigid in the coalition (the other one being flexible) - following if the coalition and the individual rationality are satisfied.
- Stand-alone, by not being part of the coalition (the other one is also stand-alone) - doing nothing if the coalition rationality is not satisfied.

Port/shipping line flexible Railway rigid	Both flexible (Not necessary)
Port/shipping line rigid Railway flexible	Both Rigid (Not into coalition, both stand-alone)

Figure 9 The strategy matrix

Basically, the actor must check not only the profit gains based on the balance between the gains from joining the coalition and the increasing cost of being flexible but also the level of flexibility the other actor can achieve, compared with its own flexibility. In the end, the decision of being flexible or rigid, or even stand-alone, will depend on the ~~dedicated~~ balance of interests between the maritime side and the railway side, which will go beyond the scope we discussed.

- Limitations of the approach

First, although the mechanism (first part) generally indicates the potential to increase the total payoffs, and the cost/profit allocation would probably (individual rationality is not always guaranteed by this approach) encourage flexibility, there is no “mathematical model” link between the two parts. In other words, the ideal situation of increasing payoffs may not imply the most flexibility-rewarding situation or vice versa. However, the cost/profit allocation approach has the potential to contribute to the reduction of supply-chain-wide costs, including total costs and lead time, if the situation is carefully checked and properly organized.

Second, the model does not take into consideration several practical limitations, such as the exclusion of a ‘port’ actor in the approach (the ‘port’ is attached to one of the two partners to simplify the model, which also avoids the restriction of Shapley value in the vertical collaboration). Therefore, our approach might not fully capture the complexity of a real-life setting. In the hypothetical situation of one shipping line-one port-one railway company, the exclusion of a specific ‘port’ actor could be acceptable since matching one vessel with one train does not need the involvement of the port’s flexibility. On the other hand, the reality is much more complex, given the mix of containers from multiple shipping lines carried by multiple railway operators with different schedules. In such a situation, ports must act as the buffer area to coordinate both sides by providing flexible port operations (like the cross-docking in some Distribution Centers). So, to overcome the restriction of Shapley value in vertical collaboration, the actors in a three-partner game may need to be divided into three components: the traditional function part (always functional), the flexible-flexible part, and the rigid-flexible part. By doing so, it is possible to measure the flexibility in the three-partner (or more) game.

Third, a higher frequency of port calls and railway freight services will tend to diminish the significance of introducing incentive mechanisms. This is attributed to the reduced waiting times for cargo transshipment between maritime vessels and rail transportation, which are likely to be sufficiently low. Thus, the presented model seems to be particularly appropriate in smaller ports with a small number of weekly vessel and rail calls. In case the schedule reliability of maritime vessels is not assured in larger ports, the ample availability of freight services for both inbound and outbound cargo remains a mitigating factor, and vice versa. Meanwhile, the application of the voyage bundling model (order synchronization model with soft time window) from Chapter 2 can, to some extent, solve the mismatch issues by rewarding the flexible actors.

Fourth, the ownership structure of each participant can exert a significant influence on the formulation and implementation of the incentive mechanism. For instance, private entities often exhibit a higher degree of adaptability to a flexibility-rewarding mechanism, particularly when driven by profit and cost considerations. In contrast, public entities may face greater constraints owing to regulatory, social, or investment limitations. It is important to emphasize, however, that this mechanism fundamentally represents a collaborative effort towards ensuring the seamless functioning of the supply chain through the exchange of interests, which may not be limited to cost and profit issues and other interests/criteria may pose a difference preference on the benefits allocations.

1.4 Conclusions

Given the vital importance of the coordination issues in maritime hinterland transport chains, a proper incentive mechanism is demanded to guarantee smooth, efficient, and thus highly synchronized foreland-port-hinterland connections. This paper presented the principle of an incentive mechanism to overcome the conflicting interests among actors and enhance collaboration. We also applied this principle to the coordination issues in European port-railway connections from a cost-allocating perspective.

Firstly, this paper identified that bottleneck issues in port areas are the result of a lack of coordination, originally resulting from the conflicting interests of different actors. So, a cooperative incentive mechanism is proposed and tested by comparing the two possible statuses of two partner coalitions. In the stand-alone status, the individual partner is working individually without proper collaboration with each other at the Nash equilibrium, implying the existence of conflicting interests since each partner is trying to maximize its payoffs without considering the other`s strategy. On the other hand, in the “working together” status, the two partners form a coalition with compensation to the “follower” partner, who is subject to the strategy of the “leader” partner. The comparison between the two statuses shows that the status of working together combined with the trading of chain-controlling power can gain more payoffs for both individual partners and the whole coalition than in the case of the stand-alone status.

The paper also addressed the specific coordination problem of the possible mismatches in the schedules of vessels and rail shuttles. The risks of incurring synchronization problems have increased due to the increased vessel and call sizes, poor liner schedule integrity, lengthy timetabling in rail, rigid and often full railway schedules, and the potential underperformance of ports and terminals. Based on the incentive principle, a profit allocation method is proposed to reduce the unpunctuality issues in a two-partner transport chain. Such an approach can open opportunities to shift the allocated profit towards the actor who adapted its schedule to the other actor to reduce further delays or even eliminate the delay if enough incentive exists. The method will particularly reward the more flexible partner compared to the result of the original Shapley Value.

In conclusion, this paper contributes to the contemporary development taking place in maritime hinterland transport chains. Although the concept of integrated supply chains has been widely recognized, the bounded rationality of actors in the port community can still lead to sub-optimal results. The performance of the whole chain can be compromised by the conflicting interests and individual behavior of different actors. The current development in maritime transport research indicates that individual actors should collaborate and be fully integrated into maritime supply chains. This paper contributed to this discussion by presenting a conceptual framework for a feasible incentive mechanism, which can be used as the basis for collaboration in the maritime hinterland chain in view of enhancing mutual interactions. Moreover, this chapter also contributes to the existing literature by focusing on the tension between rigid train shuttle schedules and unpunctual vessel arrival patterns (which is a specific reflection of the conflicting interest notion).

This paper can be extended into four main dimensions.

Firstly, this paper is a conceptual discussion without any empirical analysis. In the future, it will be necessary to empirically investigate the used concepts, the different kinds of agreements, and how they affect the final user`s satisfaction. The collection of operational data is essential for the comparison among different profit allocation methodologies and the loss-benefits analysis.

Second, by linking the mechanism with the restriction of cost/profit allocation, the objective of being flexible and “reducing the supply-chain-wide cost” can be realized. In other words, with a proper target function and restriction function on flexibility, minimal total cost can be obtained.

Third, for the methodological part, there are several avenues for further research. The first avenue relates to the cost changes involved in potential coalitions. Many unexpected invisible costs may occur, or many visible costs may vanish during the formation of a new coalition. Further research is needed to identify and measure these costs. Also, future research can focus on the estimation of the cost of a non-exist coalition.

Fourth, more research could be developed on the institutional and governance issues associated with the application of the incentive mechanism principle. Finding the best solution for dividing the profit/cost of a coalition is one issue. Having the partners involved accept the proposed division of costs and benefits is another issue that requires legitimate and trusted institutional structures to be in place.

Appendix

Basic assumptions:

- Payoffs = income - cost
- The income of the segmented chain is made up of two contributions (based on the Douglas production function): the effort of port-related actor 1 (PRA 1) is “a” with m% contribution to the chain and the effort of port-related actor 2 (PRA 2) is “b” with 1-m% contribution.

  Total income: $\theta a^{m} b^{1-m}$

- The division of the income follows the proportion: α for PRA 1, β for the PRA 2 ($\alpha + \beta = 1$).

  PRA 1 income: $\alpha\theta a^{m} b^{1-m}$
  PRA 2 income: $\beta\theta a^{m} b^{1-m}$
- The Cost of both actors has the same friction coefficient p. So, we can define the cost as:

  Cost of PRA 1: $\frac{1}{2}pa^2$;
  Cost of PRA 2: $\frac{1}{2}pb^2$
- Since one actor will seize more payoffs by launching a leader strategy (i.e., gain the chain-controlling power) and coordinating with the other, this actor needs to offer certain compensation to the other actor, who is motivated by this compensation (in the sequent arrangement).
- **We assume PRA 1 as the dominant actor** and the coefficient is ε, so the compensation from the PRA 1 to the PRA 2 is:

Extra cost of PRA 1: $\frac{1}{2}\varepsilon pb^2$

- The coefficients are all non-negative and constant.

- **Nash equilibrium:**

$$payoff_{PRA\,1} = \alpha\theta a^{m} b^{1-m} - \frac{1}{2}pa^2 \qquad (1)$$

$$payoff_{PRA\,2} = \beta\theta a^{m} b^{1-m} - \frac{1}{2}pb^2 \qquad (2)$$

Both actors will maximize their payoffs: $\frac{\partial payoff_{PRA\,1}}{\partial a} = 0$ and $\frac{\partial payoff_{PRA\,2}}{\partial b} = 0$.

The maximum payoffs in Nash equilibrium are:

$$payoff_{chain-Nash} = \frac{\theta^2}{p}[(1-m)\beta]^{1-m}\left(\frac{m}{1+m}\right)^{m}(2\alpha)^{m} \qquad (3)$$

$$payoff_{PRA\,1} = \frac{\alpha}{m+1} * payoff_{chain-Nash} \qquad (4)$$

$$payoff_{PRA\,2} = \frac{1+m}{2} * \beta * payoff_{chain-Nash} \qquad (5)$$

- **Modified Stackelberg competition (assume PRA 1 as the leader):**

$$payoff_{PRA\,1}{}' = \alpha\theta a^{m} b^{1-m} - \frac{1}{2}pa^2 - \frac{1}{2}\varepsilon pb^2 \qquad (6)$$

$$payoff_{PRA\,2}{}' = \beta\theta a^{m} b^{1-m} - \frac{1}{2}pb^2 + \frac{1}{2}\varepsilon pb^2 \qquad (7)$$

Both actors also maximize their payoffs: $\frac{\partial payoff_{PRA\,1'}}{\partial a} = 0$ and $\frac{\partial payoff_{PRA\,2'}}{\partial b} = 0$.

$$payoff_{chain-Stackelberg} == \frac{\theta^2}{p}[(1-m)\beta]^{1-m}\left(\frac{m}{1+m}\right)^{m}\left(\frac{1}{1-\varepsilon}\right)^{1-m}\left[2\alpha - (1-m)\frac{\varepsilon}{1-\varepsilon}\beta\right]^{m} \qquad (8)$$

$$payoff_{PRA\,1'} = \frac{1}{2}\left[\frac{2\alpha-(1-m)\frac{\varepsilon}{1-\varepsilon}\beta}{m+1}\right] * payoff_{chain-Stackelberg} \tag{9}$$

$$payoff_{PRA\,2'} = \frac{1+m}{2}\beta * payoff_{chain-Stackelberg} \tag{10}$$

- **Comparison between the Nash equilibrium and Stackelberg competition**

The chain payoff comparison (the group incentive):

$$payoff_{chain-Nash} - payoff_{chain-Stackelberg} \leq 0$$

The individual payoff comparison (the personal incentive):

$$payoff_{PRA\,1'} - payoff_{PRA\,1} < 0$$
$$payoff_{PRA\,2'} - payoff_{PRA\,2} < 0$$

References

Álvarez-SanJaime, Ó., Cantos-Sánchez, P., Moner-Colonques, R. and Sempere-Monerris, J.J., 2013. Vertical integration and exclusivities in maritime freight transport. *Transportation Research Part E: Logistics and Transportation Review*, *51*, pp.50-61.

Álvarez-SanJaime, Ó., Cantos-Sanchez, P., Moner-Colonques, R. and Sempere-Monerris, J.J., 2015. The impact on port competition of the integration of port and inland transport services. *Transportation Research Part B: Methodological*, 80, pp.291-302.

Baccelli, O. and Morino, P., 2020. The role of port authorities in the promotion of logistics integration between ports and the railway system: The Italian experience. *Research in Transportation Business & Management*, 35, p.100451.

Bergantino, A., & Coppejans, L., 1997, A game theoretic approach to the allocation of joint costs in a maritime environment: a case study. University of Wales

Bichou, K., 2006. Review of port performance approaches and a supply chain framework to port performance benchmarking. *Research in Transportation Economics*, *17*, pp.567-598.

Boschian, V., M. Dotoli, M.P. Fanti, G. Iacobellis, and W. Ukovich. 2011. A metamodeling approach to the management of intermodal transportation networks. *IEEE Transactions on Automation Science and Engineering* 8 (3): 457–469.Return to ref 2011 in article

Cacchiani, V., Caprara, A., & Toth, P., 2010, Scheduling extra freight trains on railway networks. *Transportation Research Part B: Methodological*, 44(2), 215-231.

Cachon, G. P., & Lariviere, M. A., 2005, Supply chain coordination with revenue-sharing contracts: strengths and limitations. *Management science*, 51(1), 30-44.

Carbone, V., & Martino, M. D., 2003, The changing role of ports in supply-chain management: an empirical analysis. *Maritime Policy & Management*, 30(4), 305-320.

Cullinane, K., Haralambides, H., Notteboom, T., 2023, Short-term effects and longer-term impacts of the COVID-19 pandemic on the international shipping and port industries, *International Journal of Transport Economics*, l (1-2), 45-88

Cruijssen, F., Cools, M., & Dullaert, W., 2007, Horizontal cooperation in logistics: opportunities and impediments. *Transportation Research Part E: Logistics and Transportation Review*, 43(2), 129-142.

Dai, B., & Chen, H., 2012, Profit allocation mechanisms for carrier collaboration in pickup and delivery service. *Computers & Industrial Engineering*, 62(2), 633-643.

De Borger, B. and De Bruyne, D., 2011. Port activities, hinterland congestion, and optimal government policies the role of vertical integration in logistic operations. *Journal of Transport Economics and Policy (JTEP)*, *45*(2), pp.247-275.

De Langen, P. W., & Sharypova, K., 2013, Intermodal connectivity as a port performance indicator. *Research in Transportation Business & Management*, 8, 97-102.

De Langen, P.W. and Chouly, A., 2004. Hinterland access regimes in seaports. *European Journal of Transport and Infrastructure Research*, *4*(4).

De Langen, P.W., 2007. Port competition and selection in contestable hinterlands: the case of Austria. *European Journal of Transport and Infrastructure Research*, *7*(1), pp.1-14.

Demirci, E. 2003. Simulation modelling and analysis of a port investment. *Simulation* 79 (2): 94–105.

Dias, J.Q., Calado, J.M.F. and Mendonça, M.C., 2010. The role of European «ro-ro» port terminals in the automotive supply chain management. *Journal of Transport Geography*, *18*(1), pp.116-124.

Dowd, T.J. and Leschine, T.M., 1990. Container terminal productivity: a perspective. *Maritime Policy & Management*, *17*(2), pp.107-112.

Fransoo, J. C., & Lee, C. Y., 2013, The critical role of ocean container transport in global supply chain performance. Production and Operations Management, 22(2), 253-268.

Ge, J., Wang, X., Shi, W. and Wan, Z., 2020. Investigating the practices, problems, and policies for port sea–rail intermodal transport in China. *Transportation Research Record*, 2674(6), pp.33-44.

Hoshino, S., Ota, J., Shinozaki, A. and Hashimoto, H., 2007. Improved design methodology for an existing automated transportation system with automated guided vehicles in a seaport container terminal. *Advanced Robotics*, *21*(3-4), pp.371-394.

Kiani, M., Sayareh, J. and Nooramin, S., 2010. A simulation framework for optimizing truck congestions in marine terminals. *Journal of Maritime Research*, *7*(1), pp.55-70.

Kulak, O., O. Polat, R. Gujjula, and H.O. Günther. 2013. Strategies for improving a long-established terminal's performance: A simulation study of a Turkish container terminal. *Flexible Services and Manufacturing Journal* 25 (4): 503–527.

Lam, L., Siu, J., & Song, D. W., 2013, Seaport network performance measurement in the context of global freight supply chains. *Polish Maritime Research*, 20(Special Issue), 47-54.

Lee, E., Nam, H. and Song, D.W., 2012. Defining maritime logistics and its value.

Malone, T.W. and Crowston, K., 1994. The interdisciplinary study of coordination. *ACM Computing Surveys (CSUR)*, *26*(1), pp.87-119.

Morvant, C., 2014, Is freight really flexible in the timetabling process for a mixed-use rail network? Some considerations based on French experience. *In TRA-Transport Research Arena* (p. 10p).

Notteboom, T. and Rodrigue, J.P., 2012. The corporate geography of global container terminal operators. *Maritime Policy & Management*, 39(3), pp.249-279.

Notteboom, T. E., & Rodrigue, J. P., 2005, Port regionalization: towards a new phase in port development. *Maritime Policy & Management*, 32(3), 297-313.

Notteboom, T. E., & Vernimmen, B., 2009, The effect of high fuel costs on liner service configuration in container shipping. *Journal of Transport Geography*, 17(5), 325-337.

Notteboom, T. E., 2006, The time factor in liner shipping services. *Maritime Economics & Logistics, 8(1)*, 19-39.

Notteboom, T., Pallis, A. and Rodrigue, J.P., 2022. *Port economics, management and policy*. Routledge.

Notteboom, T., Pallis, A., Rodrigue, J. P., Disruptions and resilience in global container shipping and ports: COVID-19 pandemic vs. 2008-2009 financial crisis, *Maritime Economics and Logistics*, 23(2), 179–210

Notteboom, T.E., Parola, F., Satta, G. and Pallis, A.A., 2017. The relationship between port choice and terminal involvement of alliance members in container shipping. Journal of *Transport Geography*, 64, pp.158-173.

Chapter 2 Horizontal collaboration among container shipping lines: voyage integration and benefit sharing

Abstract

Over the past decades, liner shipping companies have entered shipping alliances because of strategic and operational benefits. The formation of shipping alliances is further enhanced by challenges in terms of overcapacity and environmental pressures. Within an alliance, consolidating the voyage of container ships may help shipping lines seek additional marginal gains from collaboration due to the economies of scale and network effects. In this paper, we present a scenario of multiple carriers (in the shipping alliance) that operate similar liner services on the main shipping route. A theoretical framework is presented to estimate the collaboration cost and to distribute the collaborative benefits among the participating carriers as fairly as possible by using the Shapley Value. If one or more carriers reject the overall optimal arrangement, two basic solutions are given to eliminate the imbalance.

Keywords: *Cooperative game theory, Carrier, Horizontal collaboration, Shapley Value*

2.1 Introduction

Container transportation services have experienced very rapid growth, from 30 million TEUs in 1990 to 100 million TEUs in 2007 and more than 160 million TEUs in 2021 (UNCTAD, 2022). Although the capacity and cargo volume of shipping lines/alliances have increased significantly in the past decades, their profit margin does not catch up, which is mainly due to the fierce competition among shipping lines/alliances. The maritime transport of containerized cargo is often considered a highly ‘commoditized’ market as there is little differentiation possible between the services of different carriers. The level of service differentiation is particularly low among the shipping lines belonging to the same shipping alliance that jointly manage ship capacity on one or more trade routes. In the period 2009-2019, liner shipping companies were regularly confronted with decreasing profits or even losses, mainly resulting from fleet overcapacity and the associated low freight rates. Existing strategic alliances among shipping lines at that time (i.e., New World Alliance, Grand Alliance, and CKYH alliance) were not able to roll out effective capacity management programs to significantly reduce fleet capacity in line with the observed drops in demand (Notteboom et al., 2022). In March 2016, the Shanghai Containerized Freight Index (SCFI) on the Asia-North Europe trade reached an all-time low of USD 240 per TEU. The problem with low or negative operating margins is even more severe for some carriers who already have exhausted their internal potential through process optimization, cost-cutting measures, and a focus on IT (Wang et al., 2011). While shipping lines realized record profits in the period 2020-2022 due to extremely high freight rates and supply chain issues related to the COVID-19 pandemic, low freight rates and fears for vessel overcapacity re-emerged in mid-2022 (UNCTAD, 2022; Notteboom et al., 2022).

Still, horizontal collaboration (HC) between different carriers may be a promising method in view of realizing further cost reductions and efficiency gains and benefiting the most from economies of scale and network effects. Cruijssen et al. (2007) discussed the advantages of horizontal collaboration in transportation chains and the role of incentives for “alliance” formation. By integrating the “low efficient” voyages among the different liner shipping companies within the shipping alliance, carriers may be able to exploit win-win situations in that involved partners can directly enjoy cost reduction by cutting off the unnecessary (fixed) cost.

This paper presents a conceptual framework on how carriers can reduce costs by integrating voyages in an operational sense. Meanwhile, we also analyze how the benefits can be allocated to the alliance partners from a centralized perspective and adjusted based on the individual rationality of each partner.

The paper is organized as follows: we start with reviewing the literature on shipping alliances and the related works on horizontal collaboration and cost allocation methods. Next, we present a scenario and specify a cost estimation function to estimate the collaboration cost and divide the collaborative benefits among carriers by using the Shapley value. If any of the carriers reject the overall optimal arrangement, two basic solutions are given to eliminate the imbalance. We conclude by discussing the implications of the proposed approach and formulating recommendations.

2.2 Literature review

2.2.1 Shipping alliance

Since the mid-1990s, companies have been seeking to establish various forms of alliances (Panayides & Wiedmer, 2011), causing dramatic structural changes in liner shipping (see, e.g., Brooks, 2000 and Notteboom, 2004). The cooperation among the carriers primarily refers to various forms, such as liner conferences (Bennachio et al., 2007; liner conferences have been abolished in 2008 following a decision of the European Commission), alliances (see for an overview Slack et al., 2002; Notteboom et al., 2017; Ghorbani et al., 2022), and mergers (see Crotti et al., 2020). The term shipping alliance mainly refers to strategic/global alliances that utilize the concept of alliance to achieve both strategic and operational goals. In practice, horizontal collaboration in shipping alliances contains a wide range of sea-leg and land cooperative agreements, including vessel sharing, slot chartering, sailing arrangements, scheduling arrangements, and the consolidation of land facilities (Liu & Imai, 2006). This type of (horizontal) arrangement was established to cooperate at the level of the employment and utilization of ships over major global (east-west) routes, including type/size of the ship, sailing schedule and itineraries, use of joint terminals, and container coordination on a global scale (Panayides & Wiedmer, 2011). Collaboration within the shipping alliance allows the members to enjoy not only the economies of scale from the declining average cost per TEU with the increasing size of container vessels (Cullinane et al., 2000; Haralambides, 2019; Cariou et al., 2021) but also the economies of scope from the extended market coverage (Thanopoulou et al., 1999; Cruijssen et al., 2007; Panayides et al., 2011; Caschili et al., 2014) without additional investment.

Extant literature discussed the rationale for shipping lines to engage in alliances (e.g., Ryoo & Thanopoulou, 1999; Midoro & Pitto, 2000; Slack et al., 2002; Song & Panayides, 2002; Ding et al., 2005; Cariou, 2008; Frémont, 2009; Panayides et al., 2011; Huang et al., 2013; Wang, 2015; Notteboom et al., 2017; Cariou et al., 2021), mostly financial, economic, strategic, marketing, and operational. First, shipping lines can enjoy the optimization of routes and container utilization so as to improve fleet management and reduce the problem of overcapacity that often plagues the shipping industry. Second, container ships are very capital-intensive and sensitive to fuel prices and regulatory changes, so the sharing of investment costs and operating risks among carriers helps to lower the burden of fleet expansion/vessel upscaling and enhance their financial stability. Third, collaboration with other carriers in a shipping alliance can help consolidate the carrier’s market shares on certain routes or even expand the business into new markets to achieve higher market diversification. Fourth, horizontal collaboration is also beneficial to service quality (due to more comprehensive and competitive service), technology innovations (due to the high requirement of digitalization in HC), and environmental concerns due to the unit emission reduction, which is a key issue in light of potential carbon taxing for maritime transportation (Ballot et al., 2010). Besides, from a management perspective, the reviews of strategic shipping alliances by Cruijssen et al. (2007), Chen et al. (2022), and Ghorbani et al. (2022) all concluded several major factors facilitating a successful horizontal collaboration: formation of shipping alliance, finding the right partner (partner selection), allocation of gains (management of alliance), negotiation (cooperation mechanism design), coordination (synergy planning). Among these factors, some papers have addressed issues such as the stability of alliances (Song et al., 2002; Yang et al., 2011), the choice carriers have to join an alliance or opt for consolidation through mergers and acquisitions (Das, 2012), assessment of performance of shipping alliance (Rau et al., 2017; Lee,2019) and the key factors in the intra-management of shipping alliance, highlighting mutual trust/agreement and partner compatibility (Lu et al., 2006; Tan et al., 2014).

So far, the names and composition of shipping alliances have changed many times over the past twenty years as a result of mergers and acquisitions in liner shipping and changing preferences and requirements of individual shipping lines (see **Error! Reference source not found.**). Recent m ergers and acquisitions in liner shipping (such as the merger between Cosco and China Shipping into China Cosco Group, the take-over of APL by CMA CGM, and the take-over of Hamburg Sued by Maersk Line) have recently fundamentally changed the alliance landscape.

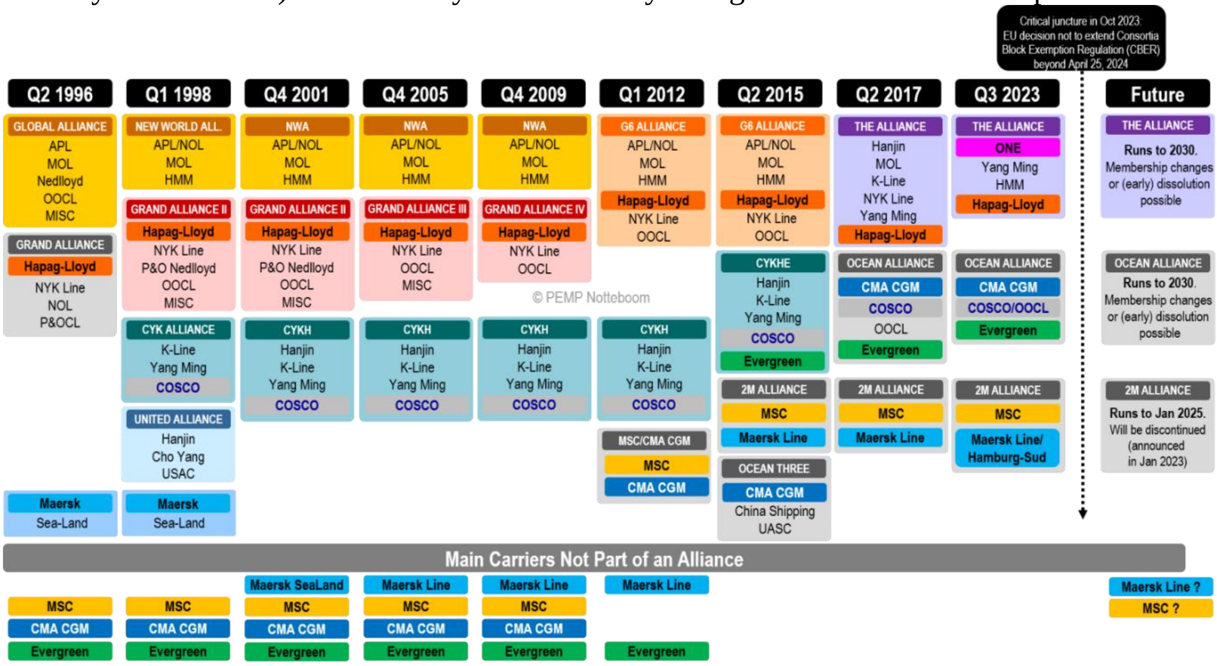

Figure 10 Evolution in alliance formation between shipping lines, period 1996-2023

Source: Notteboom et al. (2023)[1]

2.2.2 *Horizontal collaboration and the allocation of benefits*

In the past decade, the number of articles on collaborative logistics has increased greatly due to its potential to enhance cost savings for the carriers providing the transport service. Krajewska et al. (2006) reported that horizontal collaboration results in 5% to 15% cost savings in freight transportation. Guajardo et al. (2016) found even higher benefits, i.e., 6%-46%, for various industries. They all assume that the shipper will bundle the requests before submitting them to carriers instead of sending their orders/bookings individually. Meng et al. (2012), Chen et al. (2017), Zheng et al. (2015), and Shi et al. (2020) all investigate the coordination mechanism within shipping alliances on an operational level related to synergy in alliance, including sharing and allocating of ships and slots, joint-dispatching ships, collaborative-designing route network.

Extant literature investigates how the benefits (e.g., cost savings) can be shared among different partners after a successful horizontal collaboration. Sakawa et al. (2001) studied the cost allocation in the optimal plan of house material manufacturing and sale. Krajewska et al. (2006) studied cost allocation in vehicle routing for freight forwarding companies. Cruijssen et al. (2010) analyzed cost allocation in the vehicle routing problem with delivery time windows. Frisk et al. (2010) deal with cost allocation in the forest industry logistics in Sweden based on collaborative planning. Massol et al. (2010) examined gain sharing in the transportation of liquefied natural gas (LNG) by maximizing profit. Similarly, Lehoux et al. (2011) also apply the profit-maximizing strategy to the collaboration between pulp and paper producers while also allocating the benefits. Dai & Chen (2012) discuss several profit allocation methods among carriers in a carrier collaboration problem in pickup and delivery services. Lozano et al. (2013) compared the allocation method of joint cost savings of cooperation opportunities. Han et al. (2013), Huang (2013), Wang et al. (2016), Zheng

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[1] Refer to the online version of the port economics book. https://porteconomicsmanagement.org/pemp/contents/part1/ports-and-container-shipping/alliances-container-shipping/

et al. (2017), and Guo et al. (2021) all developed various modified Shapley value for profit sharing that is proportional to the contributions and Zheng et al. (2017) take the economies of scale into consideration. Vanovermeire et al. (2014) also compared multiple cost allocation methods in the vehicle routing problem. Ozener (2014) studied the cost allocation method, given the emission cost involved in the vehicle routing problem. Guajardo et al. (2016) investigate the problem of which coalition should be formed and how the cost should be allocated in a collaborative setting. Wang and Liu (2019) coordinated the rights and interests of shipping alliances from the supply chain contract perspective to ensure a win-win situation. They designed a revenue-sharing and service cost allocation contract and improved the contract with a compensation mechanism to make the distribution mechanism more effective.

Despite recent advances made in analyzing horizontal collaboration in supply chains, the literature on voyage integration and associated cost-sharing in shipping alliances is not rich. We discuss the relevant studies in section 2.3. This paper helps to fill a gap in the academic literature by investigating **voyage integration issues among carriers in an alliance setting and further cost savings allocations to promote such integration**.

2.3 The voyage integration problem

2.3.1 *Cost estimation for voyage integration*

Under the current market circumstances in liner shipping, collaboration among different carriers in a shipping alliance can be considered in view of integrating existing voyages of liner service schedules to achieve lower costs and lower emissions.

In this section, a linear programming approach is presented to show how to estimate the minimum cost of any coalition. The methodology used is adapted from Vanovermeire et al. (2014). Next, we estimate the benefits of collaboration, which is helpful for the further allocation of benefits.

For modeling purposes, we assume that the transportation demand (the number of containers) on the route is known for a certain period of time so that carriers can reallocate (confirm or cancel) ships for a certain lay-up cost and that each voyage takes place following the originally planned trip planned by the carrier on a certain date. In order to reduce the cost, one or multiple voyages could be merged into one trip. However, if voyage integration results in a change of the voyage date to an earlier or later date, shippers can be affected, and a violation cost will emerge. This violation cost is dependent on the level of violation, based on the concept of soft time windows introduced by Taillard et al. (1997). So, the cost of each trip will consist of three components: the direct transportation cost related to the number of (totally bundled) containers, the penalty cost related to the delivery time violation (from a shipper's perspective), and a carrier-specific vessel lay-up cost incurred as a result of the bundling of liner services. When the delivery time violation increases (delayed or advanced scheduled arrival time), the penalty cost should increase as well to compensate for the delay or advancement of the container delivery to shippers in terms of the schedule-violated container's value. In this research, we assume a linear relationship between penalty cost and the level of delivery time violation. Meanwhile, the more voyages are integrated, the more lay-up costs will be added to the total cost. The concept of voyage integration is demonstrated in Figure 9 by presenting a case of two voyages on Monday and one voyage on Tuesday. After integration, two scenarios can be put forward depending on the balance of total cost and penalty cost: an integration of voyages on the same day or an integration of voyages on a nearby date.

The decision variables of the model are: 1) x_{ij} indicated whether the voyage i is bundled in the trip j or not. 2) z_{jp}= whether trip j has p containers (i.e., whether to price trip j with the number of containers p or not). The objective function is to minimize the total transportation cost, which consists of three components: the direct cost of the trip (calculated based on the final number of the containers and the vessel cost), the penalty cost for deviations from the initial delivery date (with a linear function for the time violation cost), and the lay-up costs.

The model is adapted from the model on order synchronization with soft time windows (sequential model) as presented in Vanovermeire et al. (2014). We specifically take into account that carriers need to decide whether to conduct their voyages individually or to merge with other voyages on the same day, or even merge with other voyages on a different date.

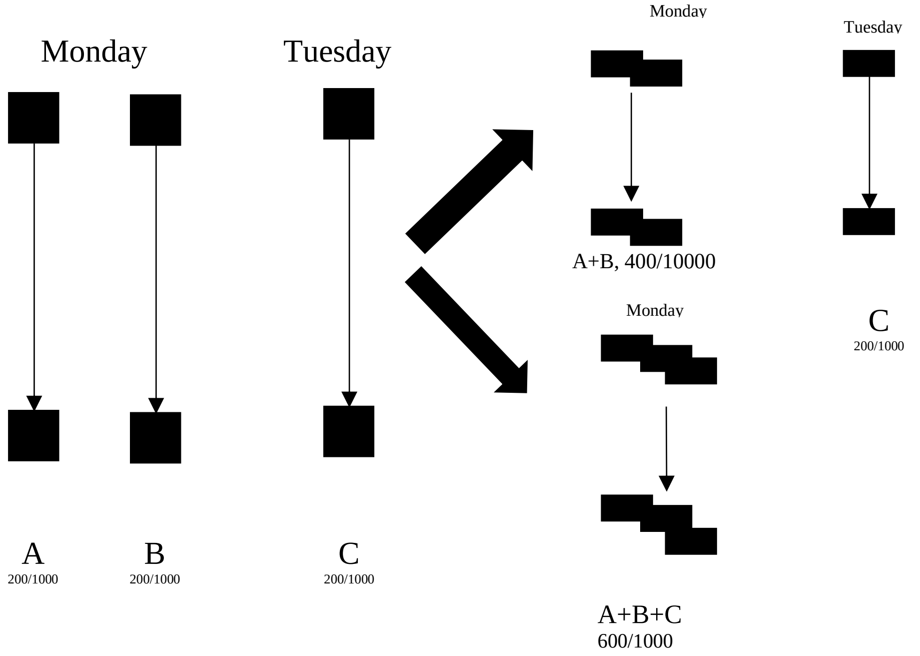

Figure 11 An example of voyage integration

Note: A, B, and C are individual liner services of shipping lines, while A+B, A+C, B+C, and A+B+C are possible combinations of merged/joint services

Table 5 An example of voyage merging – all individual trips are merged into an integrated trip

	Trip 1	Trip 2	Trip 3	Trip 4	…
Voyage 1	~~1~~ →	1			
Voyage 2		1			
Voyage 3		1 ←	~~1~~		
Voyage 4		1 ←		~~1~~	
…					1

Source: author`s own elaboration

2.3.2 *Model specification*

We present the following model description.

Let:

i: the original voyage

j: the trip (the original trip or the merged trip)

p: the number of containers

q_i: the number of containers in voyage i

d_j: the date of trip j
e_i: the deviation of delivery date, compared to the initial delivery date.
c_i: the daily cost of the deviation
tb_j: the bundling situation based on how many voyages are bundled in trip j
lc_i: the single lay-up cost
w_j: the cap of container ships
c(p): the direct transportation cost of p containers (based on the cost function in terms of p)
f_i: the original/initial delivery date
A_i: the upper boundary of the delivery date
B_i: the lower boundary of the delivery date
M: an extremely big positive number
cap: the max number of containers that a vessel can carry

The variables in the model are as follows:
x_{ij}: voyage (bundling) decision variable, whether trip j includes the voyage i or not
z_{jp}: (pricing) decision variable, whether the number of containers p are in trip j or not (so that it will be priced or not)
d_j: the actual delivery date of trip j
e_i: the deviation from the original delivery date of order i

We present the following cost-minimizing model:

$$TC(S) = Min \overset{\text{The direct transport cost}}{\sum_j \sum_p c(p) * z_{jp}} + \overset{\text{The penalty costs (both items)}}{\sum_i c_i * e_i + \sum_{\mathrm{j}} tb_j * \mathrm{lc}} \tag{1}$$

s.t.

$$\sum_j x_{ij} = 1 \quad \forall i \tag{2}$$

$$\sum_p z_{jp} = 1 \quad \forall j \tag{3}$$

$$tb_j = 0\, when\ \sum_i x_{ij} = 0\ or\ 1 \quad \forall j, \text{ integer}$$

$$tb_j = \sum_i x_{ij} - 1\, when\ \sum_i x_{ij} > 2 \ \ \forall j, \text{ integer} \tag{4}$$

$$\sum_i q_i * x_{ij} \leq cap \quad \forall j \tag{5}$$

$$d_j - M * (1 - x_{ij}) \leq f_i + B_i \quad \forall i, \forall j \tag{6}$$

$$d_j + M * \left(1 - x_{ij}\right) \geq f_i - A_i \quad \forall i, \forall j \tag{7}$$

$$e_i \geq f_i * x_{ij} - d_j \quad \forall i, \forall j \tag{8}$$

$$e_i \geq d_j - f_i - \left(1 - x_{ij}\right) * M \quad \forall i, \forall j \tag{9}$$

The objective function (1) minimizes the total cost: the direct transport cost, the penalty cost associated with a date change, and the lay-up costs due to voyage integration. Function (2) makes sure the voyage i is only bundled once. Function (3) ensures trip j is only priced once (if no containers are in the trip, then c(0)=0, making the trip cost=0). Function (4) decides on the bundling situation based on how many voyages are included in trip j. Function (5) ensures that the integrated voyages in one trip do not exceed the capacity of all container ships. Function (6) (7) limits the actual delivery date of the trip within $[f_i-A_i, f_i+B_i]$. Functions (8) and (9) allow the e_i (the deviation from the original delivery date of order i) to change.

The penalty cost for the delivery time violation is decided by $c_i * e_i$, and the penalty cost for vessel lay-up is decided by $tb_j *$ lc:

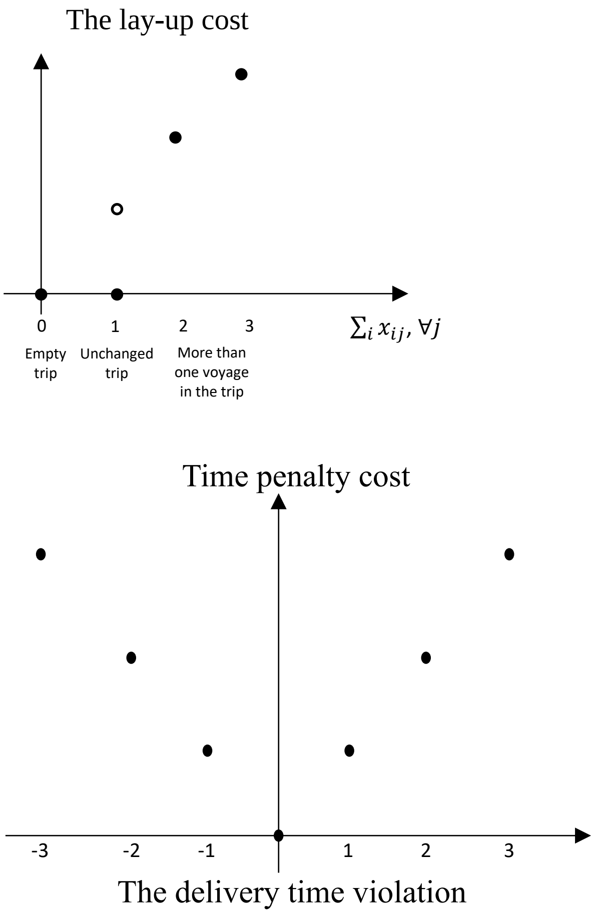

Figure 12 The lay-up cost and the time penalty cost

We assume there are three companies (A, B, C). Firstly, we solve the model individually, without any collaboration, so that we can obtain three individual costs for A, B, and C. Secondly, we solve this model for every possible coalition of two companies in order to obtain the costs of coalitions AB, AC, and BC. Finally, we solve this model again for a larger coalition among the three companies to get the cost of ABC. If there are more companies, we can keep increasing the number of possible coalitions until we reach a grand coalition between all shipping lines.

In practice, it is not always possible for the model to guarantee the minimization of the total cost since the trade-off between the cost saving from voyage integration and the penalty cost does not always favor voyage integration. For instance, in case the penalty cost for the date change and layup are too high, carriers might decide to maintain their previous service without joining any coalition**.** In this paper, based on our pre-requirement, the optimal costs of any coalition should always be lower than the sum of the costs of individual companies: $TC(Coalition) \leq \sum_{p\epsilon Coalition} TC(p)$. So there will be a difference between the integrated minimum cost and the

sum of the individual costs, which is the cost saving due to the integration of the coalition, thus $Cost\ saving = \sum_{p \epsilon Coalition} TC(p) - TC(Coalition)$.
For a three-carrier situation (A, B, C), the cost savings for all potential coalitions are presented in Table 4.

Table 6 An example of cost saving in a three-carrier coalition

Possible Coalition	Total cost (coalition)	Cost saving (coalition)
{A}	TC(A)	0
{B}	TC(B)	0
{C}	TC(C)	0
{AB}	TC(AB)	TC(A)+TC(B)-TC(AB)
{BC}	TC(BC)	TC(B)+TC(C)-TC(BC)
{AC}	TC(AC)	TC(A)+TC(C)-TC(AC)
{ABC}	TC(ABC)	TC(A)+TC(B)+TC(C)-TC(ABC)

In the next section, we discuss the allocation of cost savings.

2.4 The problem of cost-saving allocation

2.4.1 *Problem statement*

Since voyage integration can provide cost-saving opportunities, the issue of how to allocate those savings among different carriers becomes very important for the future sustainability of the coalition.

The most natural way to deal with cost allocation is based on proportions, which is quite popular in practice since it is easy and intuitive. However, this simple method sometimes cannot provide an appropriate incentive for the carriers to participate in a collaboration. For example, in coalition A+B+C of Figure 9, the cost allocated to C should be less than the cost allocated to A or B because C changed its voyage time from Tuesday to Monday, to obtain an integration with the voyage of A+B. Meanwhile, the cost will be evenly distributed among the three partners due to the equal number of containers in this combined trip. Therefore, a more comprehensive approach is needed to remedy the problem of fairness. Cooperative game theory may help to solve this problem since it is able to consider the marginal contribution of a partner`s entrance from a more theoretical perspective.

Song and Panayides (2002) were the first to apply this theory to liner shipping. They used a conceptual framework of cooperative game theory to understand strategic alliances in liner shipping. However, they did not develop this further into the allocation of benefits. Agarwal and Ergun (2010) made a further step in their study of optimizing shipping line network and resource allocation. They introduce a “side” payment as an incentive for the carriers to motivate them to act in the best interest of the alliance while maximizing their own profits. Apart from the above studies, there are very few studies in the field of liner shipping that consider the application of cooperative game theory. In the field of freight transportation (mainly trucking), cooperative game theory is widely applied by researchers in collaborative logistics, as mentioned earlier in section 2.

Among all the different Cooperative game theory methods, this paper will focus on the Shapley Value method, which is the most commonly used concept in literature (Guajardo et al., 2016).

2.4.2 *Allocation methods*

There are various allocation methods available, including the proportional method, Shapley Value, Nucleolus, etc. We first discuss the most commonly used methods before choosing the preferred method in this paper, i.e., the Shapley Value.

The most commonly used method is the "proportional method". It is a traditional way of dividing the cost/cost savings. The assigned cost to partner i is based on the proportion of partner i in the total costs.

$$x_i = \alpha_i * TC(N) \qquad i\forall N$$

Since this method is based on proportion, the cost savings allocated to company A is based on the proportion of the number of containers carried by A divided by the total number of containers. The benefits allocated to the company i can be written as follows:

$$Cost\ saving_i = \frac{the\ number\ of\ container_i}{total\ number\ of\ containers}\{\sum\nolimits_{p\epsilon Coalition} TC(p) - TC(Coalition)\}$$

Due to its proportional feature, this allocation method is not suitable for more complex situations in which some partners have higher costs due to their flexibility in dealing with the needs of the other partners. For instance, carrier A integrates its voyage (200 containers) into the grand coalition (total 1000 containers), so carrier A should receive 1/5 of the total cost saving/total cost, which may not be able to provide enough incentives for the individual carrier A to integrate its voyage(s) because of other potential additional costs when joining the coalition.

Shapley Value. This method (Shapley, 1953) allocates the weighted average of the marginal costs to the partner when it enters all possible coalitions.

$$x_i = \sum_{S\in N\backslash i} \frac{|S|!\,(|N| - |S| - 1)!}{|N|!} \times [TC(S) - TC(S\backslash i)] \qquad i\forall N$$

In this paper, the Shapley value is chosen to divide the (coalition) cost given the following advantages (Krajewska et al., 2008): (1) uniqueness: it guarantees there is no hypothetically better solution for players so that no further room is left for the players to advance to a better allocation. (2) the relative ease of implementation: Shapley value presents a simpler formula than many other methods that need solving through linear programming (e.g., compared to Nucleolus). (3) fairness: it can ensure individual rationality, and it solely considers collaborative productivity when determining its share of the gains (Loehman et al., 1974). However, the Shapley value cannot always guarantee a core (Shapley, 1971): there may not exist a coalition that can offer a stable allocation solution. In that case, we have an empty core.

For a three-partner allocation game, the cost saving allocated to partner A is as follows:

$$Cost\ allocated_A = \tfrac{1}{3}(TC(A) - 0) + \tfrac{1}{6}\big(TC(AB) - TC(B)\big) + \tfrac{1}{6}(TC(AC) - TC(C)) + \tfrac{1}{3}(TC(ABC) - TC(BC))$$

$$CS_A = TC(A) - Cost\ allocated_A$$

2.4.3 *The adjustments in the cost saving allocation*

In the coalition estimation model, the minimal total cost is guaranteed and positioned between the cost savings from economies of scale and the marginal penalty cost for the carriers. The cost saving is defined by the difference between the allocated cost and the previous "stand-alone" cost. This solution will work perfectly in a centralized mode in which the shipping alliance can firmly control the coalition of carriers. In other words, the model can ensure group rationality when the group of carriers (the "shipping alliance") is acting as one entity.

However, in a decentralized mode, the individual carrier may reject the overall optimal arrangement generated by the model if the specific carrier's penalty cost exceeds its cost-saving received from the coalition:

$$The\ penalty\ cost\ for\ delivery\ time\ violation\ and\ laying - up_i > TC(i) - Cost\ allocated_i.$$

So, there are two solutions for this problem: (1) negotiation among the carriers and (2) the allocation of cost savings with a change in the overall arrangement. It is hard to say which of the two solutions is best. In practice, before collaborating, carriers decide on what they think seems like the best solution. This decision is based on their understanding, the result of estimating hypothetical costs, the pre-agreement, and/or other prerequisites.

2.4.4 *Negotiation among the carriers*

This method might be very time-consuming for the carriers but offers overall the most optimal cost savings. The carriers who receive positive cost-saving/gains (i.e., the cost saving is bigger than the individual penalty cost) need to compensate for the negative gains of the other carriers if the gains related to the removal of the carriers with negative gains from the alliance are lower than the updated gains of the carriers having a positive gain after compensation (i.e., the concept of net gain introduced by Liu & Imai, 2005). In other words, the removal or quitting of 'negative net gain' carriers from the coalition will depend on its marginal effect on the net gains of the 'positive gain' carriers as a result of the quitting.

$$Individual\ Net\ gain_i = the\ cost\ saving_i - the\ penalty\ cost_i$$

So, there are two possible scenarios.

First, the "negative net gain" carriers quit the coalition, and then the model needs to be resolved and reallocate those cost savings among the rest of the carriers until reaching a stable result. In this case, the optimal arrangement is renewed by "expelling" the unsatisfied ones, and the new result may not yield better outputs.

Second, the "negative net gain" carriers may stay in the coalition and trade with the "positive net gain" carriers to get enough compensation, for instance, by accepting other agreements or exchanging market share. In this case, certain invisible "assets" are taken into consideration and paid by the carriers with a positive net gain to the carriers facing a negative net gain as a return for staying in the coalition.

In practice, certain vessel-sharing agreements (VSA) in shipping alliances are examples of the second scenario. ONE (K-LINE, MOL, and NYK merged) and Hapag-Lloyd in the alliance serve as examples. In 2017, Hapag-Lloyd dedicated 96% of its slot capacity to the THE Alliance, and ONE dedicated the same 96% of its slot capacity to the THE Alliance too. Meanwhile, the two-liner shipping companies focus on different main routes: Hapag-Lloyd, from Germany, mostly focused on the transatlantic, Europe-South America, intra-Europe, and Europe-Asia routes. NYK, originating from Japan, was mainly active on the transpacific, Asia-Europe, and intra-Asia routes. Extending the service coverage of each carrier through alliance cooperation may come at a price for the VSAs in the alliance (NYK report, 2017)

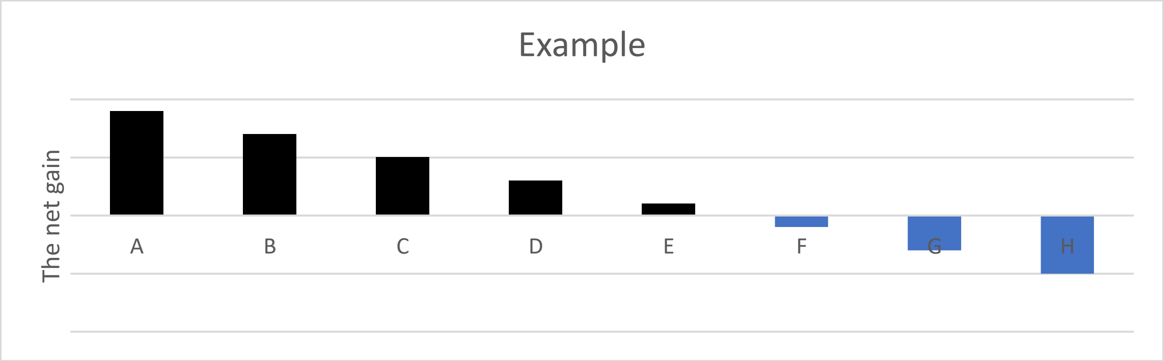

Figure 13 An example of the "positive gain" carriers and "negative gain" carriers in the coalition

Source: Authors

2.4.5 *The allocation of cost savings with a change in the overall arrangement*

For the "negative net gain" carriers, the penalty costs (time violation cost and the laying-up cost) exceed the cost savings from the coalition. Thus, it will be helpful to restrict certain most affected voyage integrations to avoid elevated penalty costs.

After initially determining the net gain for individual carriers, we need to:
(1) Choose the most "negative-gain" carrier, e.g., *i*.
(2) List all the voyages of carrier *i*, in terms of cost savings.
(3) Reduce the allowed delivery time range by 1 day for the most "negative cost-saving" voyage.

The steps are as follows. First, we need to solve the model, determining the net gains for each carrier. Then, if any "negative net gain" carrier exists, steps (1), (2), and (3) are repeated until there is no "negative net gain' carrier left.

This solution is trying to find a balance in view of satisfying all individual carriers (especially those with negative net gains) while keeping a minimum total cost, which is still higher than that in the centralized mode but still better than no integration.

2.5 Numerical example

In this section, a simple experiment is carried out to study the proposed approach. We assume there are five voyages offered by two different shipping lines between the same origin and destination but with different configurations.

We also assume the total cost of a voyage consists of fixed cost per voyage and variable cost per TEU: e.g., cost (voyage A) = 800+1*3000 = 3800. Cutting the fixed cost per voyage is the motivation for voyage integration.

Table 7 Base data for numerical example

Carriers	Voyage	Delivery date	No. containers	Vessel`s size	Delivery time violation cost/day/TEU	layup cost	variable cost for voyage/TEU	Fixed cost for voyage	stand-alone cost
1	A	1	3000	16000	0.03	700	1	800	3800
1	B	3	5000	16000	0.05	700	1	900	5900
1	C	2	2000	16000	0.02	700	1	850	2850
2	D	3	4000	16000	0.04	700	1	950	4950
2	E	5	7000	16000	0.07	700	1	1000	8000

The first step is to calculate the minimum total cost of all possible coalitions, in other words, to find the overall optimal arrangement for voyage integration. The costs of all possible coalitions represent the lowest one with/without a proper delivery time deviation among all the possible scenarios.

Table 8 The cost of the coalition and associated cost saving compared to a situation of stand-alone carriers

Voyage (coalition)	The cost of coalition	Cost saving	Voyage (coalition)	The cost of coalition	Cost saving	Voyage (coalition)	The cost of coalition	Cost saving
TC(A)	3800	0	TC(BD)	10600	250	TC(ADE)	16630	70
TC(B)	5900	0	TC(BE)	13750	100	TC(BCD)	13340	360
TC(C)	2850	0	TC(CD)	7630	170	TC(BCE)	16570	130
TC(D)	4950	0	TC(CE)	10770	30	TC(CDE)	15630	120
TC(E)	7950	0	TC(DE)	12810	90	TC(BDE)	18580	220
TC(AB)	9600	100	TC(ABC)	12380	170	~~TC(BCDE)~~	~~21320~~	~~*330*~~
TC(AC)	6540	110	TC(ABD)	14360	290	TC(ACDE)	19430	120
TC(AD)	8660	90	TC(ABE)	17570	80	~~TC(ABDE)~~	~~22340~~	~~*260*~~
TC(AE)	11770	-20	TC(ACD)	11360	240	~~TC(ABCE)~~	~~20380~~	~~*120*~~
TC(BC)	8600	150	TC(ACE)	14590	10	**TC(ABCD)**	**17100**	**400**
						~~TC(ABCDE)~~	~~25080~~	~~*370*~~

Table 6 shows that the combination of (ABCD)+(E) can minimize the total cost, which will likely be changed if the configuration is changed. Four coalitions are not further considered as the number of TEUs in these four coalitions exceeds the capacity of the ship.

The second step is to check the individual rationality by making sure that the allocated cost is lower than the stand-alone cost for each carrier, given an overall optimal situation. In Table 7, carrier 1 has voyages A, B, and C involved in the coalition. The carrier incurs a cost of 12294 when stepping into the coalition, compared to a cost of ~~12250~~ 12550 in a stand-alone situation. Therefore, the coalition results in a cost saving of 256 for carrier 1. Carrier 2, with only voyage D involved in the coalition and a stand-alone voyage E, has a cost of 12756 (i.e., 7950+4806) in the coalition scenario and 12900 (i.e., 7950+4950) in the stand-alone scenario, i.e., a cost saving of 144 when opting for the coalition. These positive cost savings provide enough incentives for the two carriers to integrate their voyages.

Table 9 The final arrangement of cost allocation compared to the stand-alone costs

Carrier	Original voyage	Stand-alone cost	SV-based cost
1	A	3800	3754
1	B	5900	5781
1	C	2850	2759
2	D	4950	4806
2	E	7950	

This simple example does not contain the additional arrangement for the “negative” gain carriers since all allocated costs are less than in the stand-alone status scenarios. For “negative” gain carriers, the costs associated with changing the delivery date or/and lay-up costs of certain voyages highly exceed the marginal gains linked to the whole voyage integration. In order to reduce the gap between gains and costs, these ‘negative-gain’ carriers need to list their voyages in the coalition in terms of cost saving to find the most negative cost-saving voyage and constrain the delivery time shifting range by 1 day: i.e., $c_i = c_i - 1$, and then solve the model and check the individual rationality again. If still not satisfied, this process has to be repeated until each carrier receives a positive cost saving. For instance, a coalition with four voyages could have a maximum of four different delivery times, but after restricting the delivery time of one voyage, the same coalition may only have three or fewer different possible delivery times.

2.6 Conclusions

Carriers are confronted with increased pressures to improve profitability and seek further cost savings. The integration of voyages between different carriers in a shipping alliance can help to reach this objective. The extant academic literature does not offer a lot of theoretical or empirical insights on the cost reduction that can be achieved through voyage integration and on how cost savings can be shared among alliance partners. In this paper, we discussed a framework for voyage integration and benefit-sharing from the perspective of cooperative game theory.

The paper reviewed the advantages of shipping alliances and reviewed cooperative game theory applications in various industries, with a specific focus on logistics collaboration. Using a scenario with multiple carriers in the shipping alliance that are running similar liner services on the main route, we presented a theoretical framework on voyage integration aimed at minimizing total costs (direct transport cost and penalty cost). Based on the features of the model optimization, a certain cost saving can be obtained only if the penalty cost is lower than the generated cost savings. Due to this feature, the cost allocation method (Shapley Value) needs to be integrated into the optimization model so that it will ensure the rationality of individual carriers by allocating enough incentives. In other words, although the overall optimal solution is achieved by the optimization model, the individual carriers may reject this voyage integration arrangement due to the associated individual rationale (negative net gains). Then, two follow-up solutions are proposed to balance the “positive gain” carriers and the “negative gain” carriers, including negotiation (without changing the overall optimal arrangement) and the re-allocation of the benefits by restoring certain “highest penalty cost” voyages (with changes in the previously optimal arrangement).

The contributions of this paper to the maritime economic literature are an attempt to optimize the voyage bundling, which achieves a balance between collective rationality and individual rationality, by integrating the concept of Shapley Value into the optimization model in a theoretical way. From the strategic perspective of the shipping alliance, the study can be useful for analyzing the stability of a shipping alliance by achieving a balance between efficiency and flexibility. The collective rationality by bundling certain voyages can generate certain benefits (e.g., cost savings). More importantly, the individual rationality, which postulates the split of cooperative benefits to each individual carrier in the coalition by Shapley Value and certain adjustments is better off than any potentials by forming any other coalitions. It is important to note that while there are many other factors influencing the stability of shipping alliances, including organizational complexity and intra-alliance competition (Midoro and Pitto, 2000), this study could serve as an initial steppingstone toward fostering mutual trust to reduce the influence of abovementioned instability factors.

Obviously, this study is a conceptual demonstration of the application of the cost allocation method to the optimization model (Voyage bundling in the cargo pool), which may deviate from reality and lack practicality. Within the optimization model, the assumption of deterministic demand, where the demand is known with certainty for a specific period of time, simplifies the modeling process and allows for precise optimization. However, it might not accurately reflect real-world situations and can have its limitations. First, the cargo demand is rarely known with absolute certainty; various factors, such as economic changes, seasonal variations, and “black swan” events (e.g., COVID-19, natural disasters), would result in fluctuations in cargo demand. Second, assuming the deterministic cargo demand will not account for the flexibility needed to adapt to changing freight-market conditions, which may lead to suboptimal solutions, make the transport chain vulnerable to risks, and affect costs and consumer services. In addition, integrating the structure of Shapley value to the optimization model will greatly amplify the computation complexity and the difficulty of collecting required data because SV requests the costs of all possible coalitions to decide the share of cost savings, and with each modification to the restriction/penalty cost will require a re-optimization (which needs tremendous computation). Accordingly, it could be interesting to apply the concept of *dynamic/stochastic/robust* vehicle routing problem to overcome the problem of deterministic/static cargo demand assumption.

Voyage integration requires full horizontal collaboration among the carriers to keep or remove their vessels in the vessel pool to obtain certain collaborative gains from economies of scale. If the penalty cost claimed by the carriers is too high, all the carriers will stay in “stand-alone” status. There is room for further research on other potential benefits of carrier coalitions, next to the cost savings linked to higher vessel utilization and a reduction in empty hauls. In this context, environmental benefits in terms of emission reduction are expected to form an additional incentive for voyage integration.

The approach presented in this paper focused on the integration of liner services in an alliance setting. The discussion was confined to integration and collaboration efforts in the maritime section of supply chains. Although carriers are co-operating in the context of shipping alliances, voyage integration also requires teamwork along the entire chain in view of realizing cost savings. Supply chain collaboration requires not only the bundling of horizontal service providers (such as carriers) but also vertical service providers. Future research can shed more light on a supply chain perspective on cost savings and delivery time needs by considering vertical collaboration schemes between the cargo origins – shippers – forwarders – carriers – inland carriers – and destination so that the marginal gains can be fairly distributed among the most affected partners.

Finally, there is room for further research on how the different features of the carriers can affect the sharing of cost savings, how the regular cost structure of the container ship is modified by the cost-saving mechanism, which governance set-up can provide a stronger control along the chains, and how to reduce the cost generated by voyage bundling, such as custom, quarantine, etc.

References

Agarwal, R. and Ergun, Ö., 2010. Network design and allocation mechanisms for carrier alliances in liner shipping. *Operations research*, *58*(6), pp.1726-1742.

Brooks, Mary R. (2000). Sea Change in Liner Shipping. Regulation and Managerial Decision-Making in a Global Industry.

Ballot, E. and Fontane, F., 2010. Reducing transportation CO2 emissions through pooling of supply networks: perspectives from a case study in French retail chains. *Production Planning & Control*, *21*(6), pp.640-650.

Benacchio, M., Ferrari, C. and Musso, E., 2007. The liner shipping industry and EU competition rules. *Transport Policy*, 14(1), pp.1-10.

Bilan, Y., Lyeonov, S., Stoyanets, N. and Vysochyna, A., 2018. The impact of environmental determinants of sustainable agriculture on country food security. *International Journal of Environmental Technology and Management*, *21*(5-6), pp.289-305.

Cariou, P. and Guillotreau, P., 2022. Capacity management by global shipping alliances: findings from a game experiment. *Maritime Economics & Logistics*, *24*(1), pp.41-66.

Cariou, P., 2008. Liner shipping strategies: an overview. *International Journal of Ocean Systems Management*, *1*(1), pp.2-13.

Caschili, S., Medda, F., Parola, F. and Ferrari, C., 2014. An analysis of shipping agreements: the cooperative container network. *Networks and spatial Economics*, *14*, pp.357-377.

Chen, J., Liu, X., Zhang, X., He, J. and Luo, L., 2017. Optimal bilateral cooperative slot allocation for two liner carriers under a co-chartering agreement. *The Journal of Navigation*, *70*(5), pp.1170-1182.

Chen, J., Ye, J., Zhuang, C., Qin, Q. and Shu, Y., 2022. Liner shipping alliance management: Overview and future research directions. *Ocean & Coastal Management*, *219*, p.106039.

Crotti, D., Ferrari, C. and Tei, A., 2020. Merger waves and alliance stability in container shipping. *Maritime Economics & Logistics*, 22, pp.446-472.

Cruijssen, F., Cools, M., and Dullaert, W. (2007). Horizontal cooperation in logistics: opportunities and impediments. *Transportation Research Part E: Logistics and Transportation Review*, 43(2), 129-142.

Cruijssen, F., et al. (2010). Supplier-initiated outsourcing: A methodology to exploit synergy in transportation. *European Journal of Operational Research*, 207(2), 763-774.

Cullinane, K. and Khanna, M., 2000. Economies of scale in large containerships: optimal size and geographical implications. *Journal of transport geography, 8*(3), pp.181-195.

Dai, B., & Chen, H. (2012). Profit allocation mechanisms for carrier collaboration in pickup and delivery service. *Computers & Industrial Engineering*, 62(2), 633-643.

Das, S.S., 2011. To partner or to acquire? A longitudinal study of alliances in the shipping industry. *Maritime Policy & Management*, *38*(2), pp.111-128.

Ding, J.F. and Liang, G.S., 2005. Using fuzzy MCDM to select partners of strategic alliances for liner shipping. *Information sciences*, *173*(1-3), pp.197-225.

Flisberg, P., et al. (2015). Potential savings and cost allocations for forest fuel transportation in Sweden: A country-wide study. *Energy*, 85, 353-365.

Frémont, A., 2009. Shipping lines and logistics. *Transport Reviews*, *29*(4), pp.537-554.

Frisk, M., Göthe-Lundgren, M., Jörnsten, K., & Rönnqvist, M. (2010). Cost allocation in collaborative forest transportation. *European Journal of Operational Research, 205(2),* 448-458.

Ghorbani, M., Acciaro, M., Transchel, S. and Cariou, P., 2022. Strategic alliances in container shipping: A review of the literature and future research agenda. *Maritime Economics & Logistics*, pp.1-27.

Ghorbani, M., Acciaro, M., Transchel, S., & Cariou, P. (2022). Strategic alliances in container shipping: A review of the literature and future research agenda. *Maritime Economics & Logistics*, *24*(2), 439-465.

Guajardo, M., & Rönnqvist, M. (2016). A review on cost allocation methods in collaborative transportation. *International Transactions in Operational Research, 23*(3), 371-392.

Guo, B., Hao, S., Cao, G. and Gao, H., 2021. Profit distribution of liner alliance based on shapley value. *Journal of Intelligent & Fuzzy Systems*, *41*(4), pp.5081-5085.

Han, L., Sun, Y.C. and Si, X.M., 2013. The mathematical modeling research of interest allocation in the third-party automobile logistics partners. *Journal of Industrial and Intelligent Information Vol*, *1*(4).

Haralambides, H. E., & Acciaro, M. (2011). Bundling transport and logistics services in global supply chains.

Haralambides, H.E., 2019. Gigantism in container shipping, ports and global logistics: a time-lapse into the future. *Maritime Economics & Logistics*, *21*(1), pp.1-60.

Huang, S.T. and Yoshida, S., 2013. Analysis of key factors for formation of strategic alliances in liner shipping company: service quality perspective on Asia/Europe route after global economic crisis. *International Journal of Economics and Management Engineering*, *7*(6), pp.1414-1418.

Krajewska, M. A., Kopfer, H., Laporte, G., Ropke, S., & Zaccour, G. (2008). Horizontal cooperation among freight carriers : request allocation and profit sharing. *Journal of the Operational Research Society, 59(11),* 1483-1491.

Krajewska, M., & Kopfer, H. (2006). Profit sharing approaches for freight forwarders: An overview. In *Proceedings of 5th International Conference on Modern Trends in Logistics* (pp. 157-161).

Lee, E.S., 2019. Improving a firm's performance within a strategic shipping alliance. *The Asian Journal of Shipping and Logistics*, *35*(4), pp.213-219.

Lehoux, N., D'Amours, S., Frein, Y., Langevin, A., & Penz, B. (2011). Collaboration for a two-echelon supply chain in the pulp and paper industry: the use of incentives to increase profit. *Journal of the Operational Research Society, 62(4),* 581-592.

Liu, M., & Imai, A. (2005). An application of modified Shapley value to ocean shipping strategic alliances. *日本航海学会論文集*, (113), 281-286.

Loehman, E. and Whinston, A., 1974. An axiomatic approach to cost allocation for public investment. *Public Finance Quarterly*, *2*(2), pp.236-250.

Lozano, S., Moreno, P., Adenso-Díaz, B., & Algaba, E. (2013). Cooperative game theory approach to allocating benefits of horizontal cooperation. *European Journal of Operational Research*, *229*(2), 444-452.

Lu, H.A., Cheng, J. and Lee, T.S., 2006. An evaluation of strategic alliances in liner shipping-an empirical study of CKYH. *Journal of Marine Science and Technology*, *14*(4), p.11.

Massol, O. and Tchung-Ming, S., 2010. Cooperation among liquefied natural gas suppliers: Is rationalization the sole objective?. *Energy Economics*, *32*(4), pp.933-947.

Meng, Q. and Wang, S., 2012. Liner ship fleet deployment with week-dependent container shipment demand. *European Journal of Operational Research*, *222*(2), pp.241-252.

Midoro, R., & Pitto, A. (2000). A critical evaluation of strategic alliances in liner shipping. *Maritime Policy & Management*, *27*(1), 31-40.

Notteboom, T. (2012). The Blackwell Companion to Maritime Economics, Wiley-Blackwell Publishing, ISBN: 978-1-4443-3024-3, p. 230-262

Notteboom, T. E. (2004). Container shipping and ports: an overview. *Review of network economics*, *3*(2).

Notteboom, T., & Merckx, F. (2006). Freight integration in liner shipping: a strategy serving global production networks. *Growth and change*, *37*(4), 550-569.

Notteboom, T., Pallis, A., & Rodrigue, J. P. (2022). *Port economics, management and policy*. Routledge.

Notteboom, T.E., Parola, F., Satta, G. and Pallis, A.A., 2017. The relationship between port choice and terminal involvement of alliance members in container shipping. *Journal of Transport Geography*, 64, pp.158-173.

NYK annual report 2017, https://www.nyk.com/english/esg/nyk/__icsFiles/afieldfile/2017/01/02/2017_nykreport_all.pdf (Accessed: 14 March 2023)

Özener, O. Ö. (2014). Developing a collaborative planning framework for sustainable transportation. *Mathematical Problems in Engineering*, *2014*.

Panayides, P.M. and Wiedmer, R., 2011. Strategic alliances in container liner shipping. *Research in transportation Economics*, *32*(1), pp.25-38.

Rau, P. and Spinler, S., 2017. Alliance formation in a cooperative container shipping game: Performance of a real options investment approach. *Transportation Research Part E: Logistics and Transportation Review*, *101*, pp.155-175.

Review of Maritime Transport 2022, https://unctad.org/publication/review-maritime-transport-2022 (Accessed: 13 March 2023).

Ryoo, D. K., & Thanopoulou, H. A. (1999). Liner alliances in the globalization era: a strategic tool for Asian container carriers. *Maritime Policy & Management*, *26*(4), 349-367.

Sakawa, M., Nishizaki, I., & Uemura, Y. (2001). Fuzzy programming and profit and cost allocation for a production and transportation problem. *European Journal of Operational Research*, *131*(1), 1-15.

Shapley, L.S., 1971. Cores of convex games. *International journal of game theory*, *1*, pp.11-26.

Shi, X., Ma, L. and Voß, S., 2020, July. On Designing a Slot Sharing E-Platform for Liner Shipping Services. In *International Conference on Human-Computer Interaction* (pp. 499-513). Cham: Springer International Publishing.

Slack, B., Comtois, C., & McCalla, R. (2002). Strategic alliances in the container shipping industry: a global perspective. *Maritime Policy & Management*, *29*(1), 65-76.

Solomon, M. M. (1987). Algorithms for the vehicle routing and scheduling problems with time window constraints. *Operations research*, *35*(2), 254-265.

Song, D.W., Panayides, P.M. (2002). A conceptual application of cooperative game theory to liner shipping strategic alliances. *Maritime Policy & Management, 29*(3), 285-301.

Tan, B.S. and Thai, V.V., 2014. Knowledge sharing within strategic alliance networks and its influence on firm performance: the liner shipping industry. *International Journal of Shipping and Transport Logistics 5, 6*(4), pp.387-411.

Thanopoulou, H.A., Ryoo, D.K. and Lee, T.W., 1999. Korean liner shipping in the era of global alliances. *Maritime Policy & Management*, *26*(3), pp.209-229.

Vanovermeire, C. & Sörensen, K. (2014). Integration of the cost allocation in the optimization of collaborative bundling, *Transportation Research Part E: Logistics and Transportation Review, Volume 72,* 125-143.

Vanovermeire, C., Sörensen, K., Van Breedam, A., Vannieuwenhuyse, B., & Verstrepen, S. (2014). Horizontal logistics collaboration: decreasing costs through flexibility and an adequate cost allocation strategy. *International Journal of Logistics Research and Applications*, *17*(4), 339-355.

Vornhusen, B., Wang, X., & Kopfer, H. (2014). Vehicle routing under consideration of transhipment in horizontal coalitions of freight carriers. *Procedia CIRP*, *19*, 117-122.

Wang, J. and Liu, J., 2019. Vertical contract selection under chain-to-chain service competition in shipping supply chain. *Transport Policy*, *81*, pp.184-196.

Wang, M., 2015. The formation of shipping conference and rise of shipping alliance. *International Journal of Business Administration*, *6*(5), pp.22-36.

Wang, X., & Kopfer, H. (2011). Increasing efficiency of freight carriers through collaborative transport planning: Chances and challenges. In *Dynamics and Sustainability in International Logistics and Supply Chain Management-Proceedings of the 6th German-Russian Logistics and SCM Workshop (DR-LOG 2011). Cuvillier Verlag, Göttingen* (pp. 41-50).

Wang, Z., Hu, H., Zeng, Q. and Li, X., 2016. Profit sharing and the stability of shipping alliances based on game theory. *Journal of Transport Economics and Policy (JTEP)*, *50*(3), pp.245-261.

Yang, D., Liu, M., & Shi, X. (2011). Verifying liner shipping alliance’s stability by applying core theory. *Research in Transportation Economics*, *32*(1), 15-24.

Zheng, J., Gao, Z., Yang, D. and Sun, Z., 2015. Network design and capacity exchange for liner alliances with fixed and variable container demands. *Transportation Science*, *49*(4), pp.886-899.

Zheng, S., Negenborn, R.R. and Zhu, X., 2017. Cost allocation in a container shipping alliance considering economies of scale: a CKYH alliance case study. *International Journal of Shipping and Transport Logistics*, *9*(4), pp.449-474.

Chapter 3 A game theoretical approach to the effects of private objective orientation and service differentiation on port authorities’ willingness to cooperate [2]

Abstract

This paper analyzes the effects of port objective orientation of port authorities and service differentiation on the capacity, service price, profits, and welfare among competing or cooperating ports. We also examine feasible combinations of these two factors (private objective level and service differentiation) **to promote port cooperation/integration**. We apply the model starting from a mixed duopoly where a landlord port (PA with public and private objectives) competes with a profit-seeking port (PA with fully private objective) with differentiated service. The results show that both the private objective level of the port authority and the service differentiation level have a significant influence on various port competition and cooperation settings. Certain combinations of these factors prove to be useful in view of cooperation among port authorities, which previously competed. The paper not only contributes to the existing literature on port competition/cooperation and the use of game theory in a port setting but also can provide valuable inputs to port devolution and cooperation discussions at the policy level.

Keywords: *mixed duopoly, service differentiation, port privatization, competition, cooperation*

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[2] This chapter is a slightly amended version of the published paper:
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3.1 Introduction

The changing business environment has led to a pattern of competition and cooperation in the port industry (Song et al., 2003). The growth of international trade and the relocation of main centers of production and consumption have resulted in growing port demand and increasing port competition levels. However, ports may opt for mergers and acquisitions and the creation of formal or informal alliances with other ports in view of strengthening their respective competitive positions (Cetin & Cerit, 2010; Donselaar et al., 2010). Port alliances can thus serve as a means to effectively compete with rival ports and to somewhat counterbalance the market power of port users, especially the large container shipping alliances (Slack et al., 2002), by means of sharing common resource/infrastructure, eliminating inefficient activities (Lim, Y. T., 2008), enjoying economies of scale, and enhancing operation (Ryoo et al., 2011). The literature on port competition and cooperation is tremendous, but we will mainly focus on the **most representing and game theoretical ones in the following literature reviews.**

Regarding port competition, it`s one of the most important studies in port economics. Generally, port competition studies can be defined into three categories. The first category of this study is to define the conceptual framework of port competition and conduct a case study by using them, for instance, Slack (1985), Song (2002), De Langen (2007), Notteboom and Yap (2012), Cullinane et al. (2005). The second one is about the empirical-based approach by measuring port performance/efficiency/competitiveness through frontal analysis, time series analysis, or other statistic/econometric methods. For instance, Haezendock and Notteboom (2002) applied SFA to measure port efficiency, while Cullinane et al. (2005) and Tongzon et al. (2005) employed the DEA model. Veldman et al. (2003) used a logit model on port choice. Yuen et al. (2013) investigated how foreign and local ownerships affect China's container terminal efficiency based on DEA analysis. Tian et al. (2015) developed an econometric model to estimate the demand growth of container shipping and measured the competitive relationship of ports. The third one is about employing a game theoretical approach to examine interaction (or policies) between/within port(s). This category can be further divided into two sections: intra-port competition between terminals, for instance, Kaselimi et al. (2011) studied the competition between the dedicated terminal and multiple-user terminals by using hoteling model, showing that the shift toward a fully dedicated terminal affects intra-port and inter-port competition among the remaining multiuser terminals, and Saeed et al. (2010) studied intra-port competition among three container terminals located in a port in Pakistan through a two-stage game model and also analyze the coalition of terminals; and inter-port competition that port are located in the same port region competing for the overlapping/similar market (hinterland and even transshipment market), which this study fell into. For instance, Yap and Lam (2006) examined the relationship between various ports in East Asia using a co-integration test based on historical data, where co-integration refers to a linear combination of variables that are non-stationary with the relationship present between them. Anderson et al. (2008) examined the port competition between Busan and Shanghai by employing a game-theoretical response model to check the interaction on capacity investment. De Borger et al. (2008) analyzed the interaction of pricing and capacity investment between two competing ports, with hinterland congestion considered. Luo et al. (2012) developed a two-stage game model to test what would happen if a new port near an existing one served the same hinterland with a focus on pricing and capacity investment. Ishii et al. (2013) examined the port competition between Busan and Kobe to determine the pricing behaviors of the two ports at each period of their capacity investment. Zhuang et al. (2014) concluded that port competition may lead to port specialization by applying a duopoly model on two ports with two types of cargo. Yip et al. (2014) built a game model where two terminal operators applied franchise rights in two adjacent seaports, showing that if both terminal operators expanded, they would become worse with an increase in inter-port competition and intra-port competition. Czerny et al. (2014) investigated the impacts of port privatization in the context of port competition on social welfare, where the two ports located in different countries handle their own cargo and transshipment cargo. Cheng and Yang (2017) studied port investment equilibrium when the competing ports have different objectives: maximizing port profit or maximizing local GDP.

Port cooperation is also an important topic in maritime economics. Many scholars have studied port cooperation problems on economic models, game theory, and operation research (Notteboom and Yang, 2017). Port cooperation can be further divided into three types: vertical cooperation, referring to upstream/downstream cooperation**. Horizontal cooperation among different ports (authorities or terminals)** and mixed cooperation (Notteboom & Rodrigue, 2005; Langen et al., 2009; Ryoo, 2011). Furthermore, Song (2002, 2003) raised a new strategic relationship as co-opetition, where competition and cooperation co-exist. Vertical integration in the shipping and port industry is typically represented by shipping lines acquiring equity stakes in terminal operating companies or directly managing terminal facilities themselves to exploit dedicated service (Haralambides et al., 2002; Soppé et al., 2009; Kaselimi et al., 2011; Notteboom et al., 2017;). As for horizontal/mixed cooperation, Donselaar et al. (2010) discussed the effect of port authority cooperation on social welfare and how the cooperation can be promoted on a national level. Wang et al. (2012) applied a game theoretical model to examine the effect of service differentiation on port integration/cooperation in the Pearl River Delta (China) from the current competing status. Saeed et al. (2011) developed a two-stage game model to examine the integration strategy among three container terminals in Karachi port in Pakistan, showing the integration may result in a higher price, while Dong et al. (2018) found that integration may reduce the marginal cost among the ports based on their assumption. Song et al. (2015) applied co-opetition theory to the motivation for the ports of Flanders (Antwerp, Zeebrugge, Ghent, and Ostend) as an emerging strategy to react toward the rapid changing market and found that size is not a significant factor for the motivation of cooperation. Wan et al. (2016) investigated the incentives and welfare implications of collaboration among local governments in landside port accessibility investment. Inoue (2018) investigates the Kobe-Osaka port alliance to assess how it works in reality and also discusses challenges and business opportunities, and Huo et al. (2018) analyze the port collaboration strategy adopted and implemented in China and identify the evolution of domestic port cooperation in China and the modes of international port cooperation of China. Among those port cooperation studies, most game theoretical-based studies are mainly related to port capacity management, which decides the marginal cost in the presence of economies of scale/scope and serves as the rationality of port cooperation and is consistent with the intuition that cooperation improves the competitiveness of port.

Among the above studies, service differentiation is involved in some of them to make the model close to reality, and it indeed plays a very important role in port competition and cooperation. Service differentiation could be due to differences in service quality or service type or even the connection to their overlapping but not identical hinterlands. The concept of service differentiation is documented extensively in microeconomic theory. From a neoclassical perspective, it can be argued that two load centers in the same multi-port gateway region are perfect substitutes for a port user if that user is willing to substitute one load center for another at a constant rate (Notteboom, 2009). The most commonly used method to analyze service differentiation is by checking the cross-price elasticity between ports. This approach has been used in a number of port pricing studies (Haralambides et al., 2001). Notteboom (2009) proposed an alternative approach to determine the service differentiation level by analyzing the revealed preference of container port users (i.e., shipping lines) in terms of demand profile (scale and growth, foreland & hinterland orientation), supply profile (Room for expansion, location, and nautical access) and market profile (market structure terminal operating business, cargo control, distribution activity in port).

Meanwhile, the governance of ports has changed dramatically since the 1980s, and many countries worldwide seek ways to lower entry barriers to allow private capital participation in ports. This has been reinforced by the 'New Public Management', which implies that several public economic sectors adopt a variety of values and management practices from the private sector (Pollitt and Bouckaert, 2003) in order to increase their efficiency and competitiveness (Pallis et al., 2007). Rather than restructuring the port ownership, the private sector in the port industry is mostly involved in concessions, represented by the increasingly common private operation of port facilities in government devolution programs (Gallego et al., 2022). On the other hand, in port devolution, port authorities have undergone a transformation in their structural model or, in some cases, ownership (as seen in the United Kingdom and Greece), with responsibilities pertaining to commercial and financial issues, the formulation and implementation of mid-term business plans, as well as the autonomous establishment of long-term strategic objectives (Brooks et al., 2006).

Port authority is the key decision maker in port devolution, but quite a few of the above researchers examined the role of port authorities (PAs) in port competition and cooperation settings. Cullinane & Song (2002) analyzed how privatization affects a port`s financial and operational performance and how PAs handle this. Heaver et al. (2000) investigated the challenges to port authority in inter and intra-port competition with the increasing influence of shipping alliances, and Donselaar et al. (2010) summarized the cost and benefits of cooperation between port authorities. While these papers give general suggestions with respect to the role of PAs in port competition and port cooperation, none of these papers develops a clear numerical relationship among the different factors relevant to PAs.

When considering the role of PAs in port competition and cooperation, it is important to consider the objectives of the PAs**.** PA objectives will shape the functions of PAs, which, in return, directly determine the role of PAs in competition and cooperation settings. World Bank (2007) defined a port authority as a "state, municipal, public or private body, which is largely responsible for the tasks…". The port authorities are normally the key decision-makers regarding port competition, cooperation, or potential transitions and are heavily influenced by the port governance and ownership structure. However, the situation differs from port to port, according to the general category (ownership structure) defined by the World Bank (2007): the private/public objective orientation: Service port (dominantly public), Tool port (intermediate zone), Landlord port (mixed public-private orientation), and fully privatized port. A typical example of a fully private port is the port of Felixstowe, whose daily operation and infrastructure have been privatized since the 1990s and are wholly owned by Hutchison Port UK, a subsidiary of HPH group. In comparison, the typical public ports can be found around the world, especially in developing countries, with many varieties. For instance, the container terminals in Shanghai are mainly owned by Shanghai International Port Group (SIPG), whose top 4 four shareholders are still state-owned companies, and its PA`s objective is to serve as a gateway port and keep as the biggest container port around the world (in other words, providing enough capacity to serve its hinterland is the priority). As for the landlord port, the port of Antwerp is a typical landlord port in that its port authority owns and manages the sites in the port area and makes them available to port companies for their activities on the basis of concession agreements. The objective of its PA is to keep a balance between promoting sustainable development and making the most efficient use of the available land, which can be interpreted as a mixed goal of purchasing profit and social welfare. However, a number of researchers argue that the functions of PAs go beyond the traditional/official definition. Notteboom & Winkelmans (2001), Chlomoudis & Pallis (2004), Brooks et al. (2004, 2006), De Langen (2008), Verhoeven (2010), Lugt et al. (2013, 2014) all suggest that PAs (and their functions) should adapt to the changing environment by developing a more pro-active facilitator role for the entire port community and to extend the reach of activities and functions beyond the port perimeter. Lugt and De Langen (2017) even suggest that PAs should move towards the commercial side, behaving like a port development company largely driven by commercial objectives. Moreover, apart from the managerial or policy-making perspectives, Tongzon et al. (2005) and Cullinane et al. (2005) both examine the effect of privatization (the private-oriented objective) on port efficiency at an operational level in favor of port privatization. Although some level of divergence exists among the above reports and studies, they agree on a key issue, i.e., the objectives of a PA, whether private or public, play a significant role in how the PA deals with challenges and opportunities in the field of competition and cooperation.

Table 10 The objectives of port authority as a function of the main governance models

Port authority objectives	***Governance model***		***Some applications***	***Strengths***	***Weaknesses***
Mainly profit-driven objective	***Private Port***		New Zealand, Australia, United Kingdom	Flexibility, market-oriented	No vision for the community and local development
Combined public and private objectives	***Landlord***	***China model***	China	Central planning, Community, and local development-oriented, joint venture development	Rigidity, bureaucracy, and scarce proactivity of the port authority
		Latin tradition	France, Italy, Spain	Community and local development-oriented PPP development	Rigidity, bureaucracy, and scarce proactivity of the PA
		Hanseatic tradition	Belgium, Germany, The Netherlands	Community and local development-oriented, Flexibility PPP development	Possibility of having a limited vision for the local development
	Tool Port		South Africa, China	Central planning, private involvement	Rigidity, absence of private partnerships (PPP), public financing
	Public Port		Ukraine, Israel, China	Central planning coordination among various national ports	Not market-oriented, rigidity, absence of PPP possibilities, heavy bureaucracy

Source: adapted from Ferrari et al. (2015)

Two basic categories of PA objectives can be distinguished: the private objective (profit-driven) and the public objective (social welfare). In practice, PAs might pursue various combinations of private and public objectives. There is a gap between the public/private objective of PAs and the ownership of the port. PAs are able to narrow this gap through various measures. Notwithstanding that most PAs cannot directly control the private objective of the port to set the service price, they can indirectly affect private operators' profits (and the service price) by changing the concession terms or taking other indirect measures. PAs can also influence the public objective by taking various market and regulation measures, including modifying regulations, attracting new expansion investments, early termination of a concession, etc., and finally adjusting the social welfare (also called the public objective).

Considering this prevailing trend, this study explores the impact of service differentiation and port ownership structure, which represents the port authority's objectives, on factors such as capacity, service prices, profits, and overall welfare. It achieves this by comparing the revenue differences between cooperation and competition scenarios within the context of a mixed duopoly. The study aims to determine the optimal conditions for forming cooperation within a mixed duopoly, primarily from the perspective of port authorities. In particular, we consider a mixed duopoly where a landlord port (PA with public and private objectives) competes with a private, profit-seeking port (PA with fully private objective) with differentiated service by defining a composite objective function under multiple types of competition. The design of including a landlord port is due to the fact that public port reform rarely goes into full privatization (Ng&Pallis, 2010), and the dynamic effect of the private level can be analyzed as well. Moreover, by comparing the payoff difference between multiple competing statuses and cooperating status, this paper provides a new perspective to examine the feasible combinations of these two factors to promote port cooperation from previous competing statuses. We recognize the following five works which can be used as closely related references. Yap and Lam (2006) applied a duopoly model to examine the competitive advantage between PSA and Port Klang & Tanjung Pelepas by estimating and comparing the per-TEU cost and price. Czerny et al. (2014) and Matusushima et al. (2014) both analyzed the decision to opt for port privatization in an environment characterized by competition between a public port and a fully private port. Xiao et al. (2012) focused on the effects of different port ownership with various objectives (profit or local profit or social welfare). Wang et al. (2012) investigated the effect of service differentiation on competition and cooperation between two private ports in quantity competition. Compared to the above studies, this paper uses similar modeling principles but extends the scenarios (including four different competing scenarios). Moreover, we apply the model in a differentiated oligopoly between a fully private port and a partial public port and their (monopolistic) cooperation to test the effects of PA`s objectives and service differentiation in various competing and cooperating scenarios and also seek feasible combinations of those two factors to promote cooperation from their previous competing status.

This paper not only fills the gap in understanding the effects of service differentiation and port authority`s objective (port ownership structure) in multiple types of competition/uniform cooperation but also extends the results into the economic motivation of port cooperation. This paper provides a good reference for policymakers to understand the consequence of differentiating port service and privatizing port (authority) under the port competition and help to seek the best situation for the port to opt for cooperation.

The paper is organized as follows. In the second section, the model of a mixed duopoly with differentiated service is defined. In the third section, we investigate the effects of private level and service differentiation on four possible port competing scenarios and also the cooperating scenario. In the fifth section, the profits/payoffs of the four scenarios are compared to those of the cooperation option. The final section gives policy implications and concludes the paper.

3.2 Model description

Assume that a landlord port (PA with public and private objectives) and a fully private port provide differentiated cargo services with some overlapping hinterland. Port 1 is the landlord-type port, which maximizes the combined goal of public and private objectives, while port 2 is the profit-seeking private port, which only focuses on the profit.

Following the consumer`s utility function, presented by Dixit (1979) and Sigh et al. (1984) $U(q_1, q_2) = q_1 + q_2 - 0.5(q_1^2 + q_1^2 + 2bq_1q_2)$, the inverse demand function can be obtained:

$$p_1 = a - q_1 - b * q_2$$

$$p_2 = a - q_2 - b * q_1$$

Where *p₁, p₂* are the prices of services of ports 1 and 2, and *q₁, q₂* are the **respective cargo volumes**. a is a positive constant, representing the maximum reservation price. b is the service differentiation level with $b \in$ *(0,1)*. When b=1, the services offered are perfect substitutes and thus highly similar (the reflection of b in reality can be found in the first section).

The consumer surplus, which represents the public interests of Port 1, could be originally obtained from the inverse demand function: (1) solve the inverse demand function to get the equilibrium price; (2) replace the price in the inverse demand function with the equilibrium price; (3) solve the updated inverse demand function to get the equilibrium quantity; (4) Calculate the upper triangle area (representing the consumer surplus).

For the cost function, we assume that both ports use a similar technology, and the marginal cost c is a positive constant: $total\ cost = c * q_i + F$, where i=1, 2 and F represents the fixed cost, and making F=0 without losing generality; and we also assume $a > c$.

The payoff of Port 1 consists of two parts: the public objective, "consumer surplus," and the profit objective. Based on the model presented by Matsumura (1998), the weight of the private objective is introduced, so the objective function for port 1 is: $R_1 = \beta * (p_1 - c) * q_1 + (1 - \beta) * \{(p_1 - c) * q_1 + CS\}$. $\beta \in$ *(0,1)* is the parameter that will define the private objective level of the port 1. When β =1, port 1 will become a profit-seeking private port, while when β =0, port 1 will become a highly social-concerned port. This parameter can be represented by the share of the private sector over the whole port asset. In other words, the inclusion of parameter β is the key to the dynamic analysis of its effect. Meanwhile, since port 2 is a profit-seeking entity, its objective is purely focused on profit: $R_1 = (p_2 - c) * q_2$.

Table 11 The parameters and explanations

Name	Explanation
a	a positive constant, and $a > c$
q_1 and q_2	The **cargo volumes** of port 1 and port 2 (reflection of port throughput)
p_1 and p_2	The prices of services of port 1 and port 2 (reflection of generalized port charges, and sometimes, the surcharge by shipping line can partly represent this)
R_1 and R_1	Outputs or payoffs of port 1 and port 2 (the composite goal)
CS	Consumer surplus, representing the public objective of port 1
B	The service differentiation, $b \in$ *(0,1) (definition can be found in the first section)*
C	The marginal cost of port 1 and port 2, a positive constant.
F	Fixed cost, and we assume F=0 for both ports
β	Private objective level of port 1, $\beta \in$ *(0,1)*

In this paper, the game runs as follows. In the first stage, each port will adopt either a quantity contract or price contract to compete with each other. In the second stage, after observing the choice of its rival port, each port will decide whether to cooperate with the rival port or remain in a competing status.

3.3 The equilibrium analysis of the sub games

Similar to Matsumura et al. (2012), we consider five possible scenarios or sub games (compared to four competing scenarios from Matsumura et al., 2012):

- Both ports optimize their outputs by adjusting the cargo volume (q-q game or Cournot competition) in section 3.1. We use the subscript *qq* to indicate the relevant results. Cournot competition only happens at the instant stage of capacity adjustment/planning between two ports in reality.
- Both ports optimize their outputs by adjusting their service prices (p-p game or Bertrand competition) in section 3.2. We use the subscript *pp* to indicate the relevant results. Bertrand competition happens at the stage of price competition with both stable capacities in reality.
- Port 1 adjusts its capacity to optimize its output, while port 2 adjusts its service price (q-p game) in section 3.3. We use the subscript *qp* to indicate the relevant results.
- Port 1 adjusts its service price to optimize its output, while port 2 adjusts its capacity to optimize its output (p-q game) in section 3.4. We use subscript *pq* to indicate the relevant results.
- Two ports form a strategic cooperation in section 3.5. We use subscript *coop* to indicate the relevant results.

It`s quite tricky if adjusting capacity is involved in the sub games since it requires this action to happen simultaneously with its rivalry’s action, while it takes time to expand/reduce capacity in reality, like climbing the steps. On the other hand, adjusting service price by port is quite common in reality, that both ports simply only charge their optimal service charges. Copenhagen-Malmo Port (CMP) is a typical strategic cooperation in that both previous competing ports form a unique “mixed port authority” to handle issues on both sides.

3.3.1 Model specification of the Cournot (q-q) game

Consider that both ports will optimize their payoffs by adjusting the cargo volume (Cournot competition). In practice, competing in quantity can be realized by adjusting port capacity. FOC for port 1 and port 2: $\frac{\partial R_1}{\partial q_1} = 0 \; and \; \frac{\partial R_1}{\partial q_2} = 0$, then we can get:

$$q_1^{qq} = \frac{a-c}{2(b+1)} \qquad q_2^{qq} = \frac{(a-c)(b+2)}{4(b+1)}$$

$$p_1^{qq} = \frac{(a-c)(-b^2+2b+2)}{4(b+1)} \qquad p_2^{qq} = \frac{(a-c)^2(b+2)^2}{16(b+1)^2}$$

$$R_1^{qq} = \frac{(a-c)^2(16+b^2+20b-5\beta b^2-12\beta b-8\beta)}{32(b+1)^2}$$

$$R_2^{qq} = \frac{(a-c)^2(b+2)^2}{32(b+1)^2}$$

Based on the symbolic function, not surprisingly, the service differentiation level has negative effects on all the functions in equilibrium, which re-confirms the effects of service differentiation in Cournot competition, $\frac{\partial q_1^{qq}}{\partial b} < 0, \frac{\partial q_2^{qq}}{\partial b} < 0, \frac{\partial p_1^{qq}}{\partial b} < 0, \frac{\partial p_2^{qq}}{\partial b} < 0, \frac{\partial R_1^{qq}}{\partial b} < 0, \frac{\partial R_2^{qq}}{\partial b} < 0.$

Moreover, the payoff of port 1 is decreasing only in the level of private objective, $\frac{\partial R_1^{qq}}{\partial \beta} < 0$, and for the rest of the functions, the private level has no effects. In other words, differentiating the ports` service (in terms of service quality, hinterland coverage, accessibility, service type, etc.) is very important for both competing ports; otherwise, repeated and similar port capacity will become a waste of money. The higher private level of port 1 will cause the overall payoffs of port 1 to decrease due to the marginal loss being smaller than the marginal profit.

3.3.2 *Model specification of the Bertrand (p-p) game*

Consider the situation that both ports will optimize their payoffs by adjusting their price (Bertrand competition). The demand function can be transformed to: $q_1 = \frac{a-p_1-a*b-b*p_2}{1-b^2}$, $q_2 = \frac{a-p_2-a*b+b*p_1}{1-b^2}$. FOC for port 1 and port 2: $\frac{\partial R_1}{\partial p_1} = 0 \; and \; \frac{\partial R_2}{\partial p_2} = 0$, then we can get:

$$q_1^{pp} = \frac{(a-c)(b+2)}{(b+1)(2+2\beta-\beta b^2)} \qquad q_2^{pp} = \frac{(a-c)(\beta+\beta b+1)}{(b+1)(2+2\beta-\beta b^2)}$$

$$p_1^{pp} = \frac{2c+2a\beta-a\beta b+\beta bc-a\beta b^2}{2+2\beta-\beta b^2} \qquad p_2^{pp} = \frac{a+c-a\beta-ab+\beta c+bc-a\beta b^2}{2+2\beta-\beta b^2}$$

$$R_1^{pp} = \frac{-(a-c)^2(\beta^3 b + \beta^3 + 2\beta^2 b^2 + 3\beta^2 b + \beta^2 + 2\beta b^3 + 4\beta b^2 - \beta b - 5\beta - 3b - 5)}{2(b+1)(-\beta b^2 + 2\beta + 2)^2}$$

$$R_2^{pp} = \frac{(a-c)^2(1-b)(\beta + \beta b + 1)^2}{(b+1)(-\beta b^2 + 2\beta + 2)^2}$$

Based on the symbolic function, the service differentiation level still plays a negative effect on both prices and profits, $\frac{\partial p_1^{pp}}{\partial b} < 0, \frac{\partial p_2^{pp}}{\partial b} < 0, \frac{\partial R_1^{pp}}{\partial b} < 0, \frac{\partial R_2^{pp}}{\partial b} < 0$. For quantity, $\frac{\partial q_1^{pp}}{\partial b} \gtreqless 0, if\ \beta \gtreqless \beta`, \beta` = 2/(2b^3 + 7b^2 + 4b - 2)$ and $\frac{\partial q_2^{pp}}{\partial b} \gtreqless 0, if\ \beta \gtreqless \beta``, \beta`` = -(2b + 3b^2 - \sqrt{(9b^4 + 28b^3 + 24b^2 + 8b + 4)} - 2)/(4(b^3 + 2b^2 + b))$. In addition, the prices are increasing with the level of private objective, $\frac{\partial p_1^{pp}}{\partial \beta} > 0, \frac{\partial p_2^{pp}}{\partial \beta} > 0$, which implies that focusing on the private objective will increase the service prices in Bertrand competition. The capacity of port1 will decrease with the level of private objective, while the capacity of port 2 will increase with the level of private objective, implying raising private objective will transfer the service from the partial public port 1 to the private port 2, $\frac{\partial q_1^{pp}}{\partial \beta} < 0, \frac{\partial q_2^{pp}}{\partial \beta} > 0$. The private level has similar effects on the ports’ revenues, $\frac{\partial R_1^{pp}}{\partial \beta} < 0, \frac{\partial R_2^{pp}}{\partial \beta} > 0$, showing that a higher private level of port 1 may also transfer the revenue from the public/private port to the private port when they are competing in price contracts.

3.3.3 *Model specification of the quantity-price (q-p) game*

Consider the situation in that port 1 chooses to adjust its capacity and port 2 chooses to adjust its service price. FOC for both, $\frac{\partial R_1}{\partial q_1} = 0 \; and \; \frac{\partial R_2}{\partial p_2} = 0$, then we can get:

$$a - c - q_1 - a*b - \beta*q_1 + b*p_2 + b^2*q_1 + \beta*b^2*q_1 = 0$$
$$a + c - 2*p_2 - b*p_1 = 0$$

After solving the equations, we get:

$$q_1^{qp} = \frac{(a-c)(2-b)}{2\beta-2\beta b^2-b^2+2} \qquad q_2^{qp} = \frac{(a-c)(1-b)(\beta+\beta b+1)}{2\beta-2\beta b^2-b^2+2}$$

$$p_1^{qp} = \frac{2c+2a\beta-b^2c-a\beta b+\beta bc-2a\beta b^2+a\beta b^3-\beta b^3c}{2\beta-2\beta b^2-b^2+2}$$
$$p_2^{qp} = \frac{a+c-a\beta-ab+\beta c+bc-b^2c-a\beta b^2-\beta b^2c}{2\beta-2\beta b^2-b^2+2}$$
$$R_1^{qp} = \frac{-(a-c)^2(\beta^3b+\beta^3+2\beta^2b^2+3\beta^2b+\beta^2+2\beta b^3+4\beta b^2-\beta b-5\beta-3b-5)}{2(b+1)(-\beta b^2+2\beta+2)^2}$$
$$R_2^{qp} = \frac{(a-c)^2(b-1)^2(\beta+\beta b+1)^2}{(2\beta-2\beta b^2-b^2+2)^2}$$

In q-p competition, the service differentiation level still has negative effects on the prices, profits, and capacity of the private port: $\frac{\partial q_2^{qp}}{\partial b} < 0, \frac{\partial p_1^{qp}}{\partial b} < 0, \frac{\partial p_2^{qp}}{\partial b} < 0, \frac{\partial R_1^{qp}}{\partial b} < 0, \frac{\partial R_2^{qp}}{\partial b} < 0$, except on q1: $\frac{\partial q_1^{qp}}{\partial b} \gtreqless 0, if\ b \gtreqless b`, b` = \frac{4*\beta-\sqrt{2}*\sqrt{(2*\beta+1)*(3*\beta+1)+2}+2}{2\beta+1}$. In other words, the effect of the service differentiation level has a U-shape, if b>=b`, then $\frac{\partial q_1^{qp}}{\partial b} \geq 0$, the capacity of port 1 will increase with the level of service differentiation; otherwise, if b<b`, then $\frac{\partial q_1^{qp}}{\partial b} < 0$, the capacity of port 1 will decrease with an increasing service differentiation level. Meanwhile, the private level has various effects, $\frac{\partial q_1^{qp}}{\partial \beta} < 0, \frac{\partial q_2^{qp}}{\partial \beta} > 0$, indicating that privatizing port 1 will decrease the cargo volume and enlarge its competitor`s volume; $\frac{\partial p_1^{qp}}{\partial \beta} > 0\ and\ \frac{\partial p_2^{qp}}{\partial \beta} > 0$ suggesting that privatizing port 1 will increase both port`s service prices, which confirms the outcomes of previous studies, Xiao et al. (2012) and Czerny et al. (2014); $\frac{\partial R_1^{qp}}{\partial \beta} < 0, \frac{\partial R_2^{qp}}{\partial \beta} > 0$ implies that we have a similar situation as in the p-p game: privatization of the port may transfer the profits from the public/private port to the private port in the q-p game.

3.3.4 *Model specification of the price-quantity (p-q) game*

Consider the situation that port 1 optimizes its revenue by adjusting its price, and port 2 optimizes by adjusting its capacity. FOC for both ports, $\frac{\partial R_1}{\partial p_1} = 0\ and\ \frac{\partial R_2}{\partial q_2} = 0$, then we can get:

$$c - p_1 + a*\beta - \beta*p_1 - b*p_2 = 0$$
$$a - c - 2*q_2 - a*b + b*p_1 + 2*b^2*q_2 = 0$$

After solving the above equations, we obtain:

$$q_1^{pq} = \frac{(a-c)(2-\beta b-b^2)}{2\beta-2\beta b^2-b^2+2} \qquad q_2^{pq} = \frac{(a-c)(\beta-b+1)}{2\beta-2\beta b^2-b^2+2}$$
$$p_1^{pq} = \frac{2c+2a\beta-ab+bc+ab^2-2b^2c-2a\beta b^2}{2\beta-2\beta b^2-b^2+2}$$
$$p_2^{pq} = \frac{a+c+a\beta-ab+\beta c+bc-ab^2+ab^3-b^3c-a\beta b^2-\beta b^2c}{2\beta-2\beta b^2-b^2+2}$$
$$R_1^{pq} = \frac{(a-c)^2(\beta^3*b^2-\beta^3+2*\beta^2*b^3+\beta^2*b^2-2*\beta^2*b-\beta^2+\beta*b^4+2\beta b^3-5\beta b^2-4\beta b+5\beta+b^4-3b^2-2b+5)}{2(2\beta-2\beta b^2-b^2+2)^2}$$
$$R_2^{pq} = \frac{\left(1-b^2\right)(a-c)^2(\beta-b+1)^2}{(2\beta-2\beta b^2-b^2+2)^2}$$

A few remarks are in order. The capacities of the two ports will decrease if port 1 is privatized more, $\frac{\partial q_1^{pq}}{\partial \beta} < 0, \frac{\partial\ q_2^{pq}}{\partial \beta} < 0$; meanwhile, the price will also increase with the privatization level, $\frac{\partial p_1^{pq}}{\partial \beta} > 0, \frac{\partial p_2^{pq}}{\partial \beta} > 0$. However, privatizing Port 1 will decrease both ports` profits, $\frac{\partial R_1^{pq}}{\partial \beta} < 0, \frac{\partial R_2^{pq}}{\partial \beta} < 0$. The increasing service similarity, b, unsurprisingly decreases both ports` profits, $\frac{\partial R_1^{pq}}{\partial b} < 0, \frac{\partial R_2^{pq}}{\partial b} < 0$, and also the service price of port 2, $\frac{\partial p_2^{pq}}{\partial b} < 0$. However, service differentiation is non-monotonous for the capacity of port 1 and 2, and the service price of port 1, $\frac{\partial q_1^{pq}}{\partial b} \gtreqless 0,\ if\ b \gtreqless b``$, $b`` = \frac{2-\sqrt{2(1-3\beta-2\beta^2)}}{1+2\beta}$, $\frac{\partial q_2^{pq}}{\partial b} \gtreqless 0,\ if\ b \gtreqless b```$, $b``` = \frac{3\beta+2\beta^2-\sqrt{(2\beta+1)(\beta+1)(2\beta^2+3\beta-1)}}{2\beta+1}$, $\frac{\partial p_1^{pq}}{\partial b} \gtreqless 0,\ if\ b \gtreqless b````, b```` = \frac{2-\sqrt{2(-2\beta^2-3\beta+1)}}{2\beta+1}$.

3.3.5 Model specification for strategic Cooperation between two ports

Consider a situation where the two ports choose to cooperate strategically by adjusting capacity or price. In this case, the two ports can be considered as one entity, which yields the same profit either in quantity or price contract, with the same capacity and price. However, due to the nature of "strategic cooperation", they will still keep their own profits to themselves.

FOC for both ports:
$\frac{\partial(R_1+R_2)}{\partial q_1} = 0\ and\ \frac{\partial(R_1+R_2)}{\partial q_2} = 0$ or $\frac{\partial(R_1+R_2)}{\partial p_1} = 0\ and\ \frac{\partial(R_1+R_2)}{\partial p_2} = 0$, we can get the same results:

$$q_1^{coop} = \frac{(a-c)}{(\beta+1)(b+1)} = q_2^{coop}$$

$$p_1^{coop} = \frac{(c+a\beta)}{\beta+1} = p_2^{coop}$$

$$R_1^{coop} = \frac{(a-c)^2}{(\beta+1)^2(b+1)} \qquad R_2^{coop} = \frac{(a-c)^2\beta}{(\beta+1)^2(b+1)}$$

Note that the service differentiation level has no effect on the price because their strategic cooperation is monopolistic and able to control the price, regardless of service differentiation. For the remaining parameters, cargo volume and individual profits, service differentiation (similarity) still has a negative effect, $\frac{\partial q^{coop}}{\partial b} < 0, \frac{\partial R_1^{coop}}{\partial b} < 0, \frac{\partial R_2^{coop}}{\partial b} < 0$. Moreover, the privatization of Port 1 will shrink the total cargo volume but boost the price, which confirms previous studies, Xiao et al. (2012) and Czerny et al. (2014), $\frac{\partial q^{coop}}{\partial \beta} < 0, \frac{\partial p^{coop}}{\partial \beta} > 0$. As mentioned earlier, the privatization of Port 1 will also transfer certain profits from the public/private port to the private port, $\frac{\partial R_1^{coop}}{\partial \beta} < 0, \frac{\partial R_2^{coop}}{\partial \beta} > 0$.

3.4 The feasible combination of private level and service differentiation for promoting cooperation

In this section, we compare the port`s profit on the equilibrium between the cooperation status and the competing status to promote the opportunity of cooperation by searching for feasible combinations of private level and service differentiation. Besides, the relevant parameters in various competing statuses are compared to those in co-operation status to show the marginal difference by cooperating. All the figures below are based on the calculations by Matlab_R2015b, subject to all the possible combinations $\{\beta, b\}$, which are private objective level: $\beta \in (0,1)$ and service differentiation: $b \in (0,1)$.

- ***Co-operation potential under the Cournot (q-q) game***

We found that under Cournot competition, the two ports are unlikely to cooperate in a strategic alliance since port 1 can always benefit from the cooperation, while port 2 always faces profit loss if it moves from competition to cooperation, $R_1^{coop} - R_1^{qq} > 0$, and $R_2^{coop} - R_2^{qq} < 0$. So, unless port 1 is willing to compensate port 2 for its loss in forming the alliance, they will never cooperate.

Assuming a=100, c=2 (a and c do not actually affect the result since the common part $(a-c)^2$ will be removed when comparing), then the revenues of the two PAs can be obtained, subject to $\beta \in (0,1)$ and $b \in (0,1)$, see ***Figure 14***. The upper curve surface is the marginal revenue (pay-off difference from competition and cooperation) of PA1 to cooperate, which is always bigger than 0. The lower curve surface is the marginal revenue (same as above) of PA2 to cooperate. If PA1 has a highly public-oriented objective and its services are totally different, the extreme situation exists where maximizing the revenue difference between PA1 and PA2, makes PA2 extremely unwilling to cooperate.

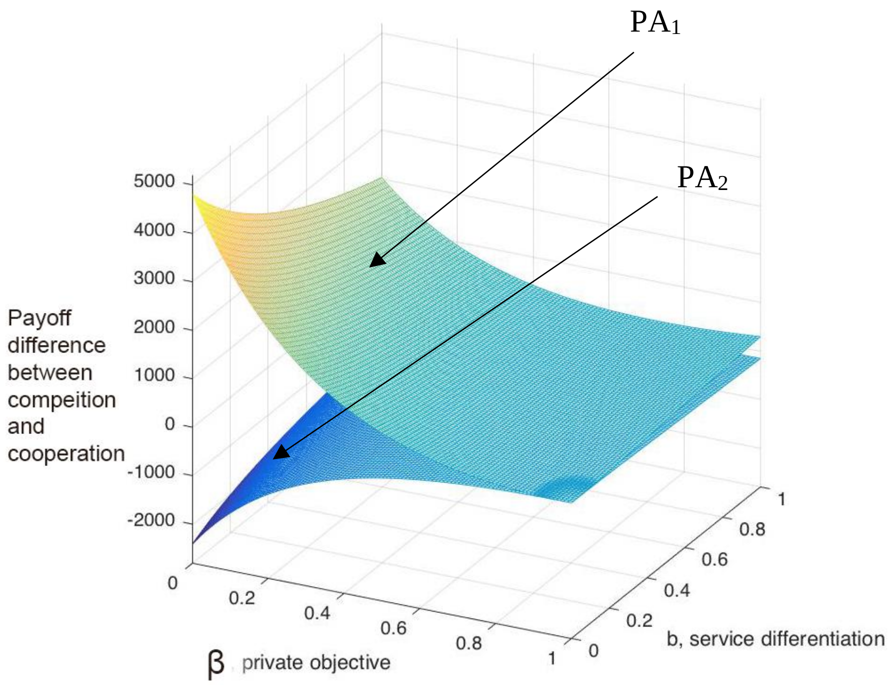


Figure 14 Outcome for q-q game, assuming a=100, c=2

Source: Authors` own elaboration

- ***Co-operation potential under the Bertrand (p-p) game***

The same methodology and signs are applied to the p-p game, and the results are presented in ***Figure 15***:

$$R_1^{coop} - R_1^{pp} = \frac{(a-c)^2\alpha}{2(\beta+1)^2(b+1)(-\beta b^2+2\beta+2)^2}$$

$$\alpha = \beta^5 b + \beta^5 + 2\beta^4 b^2 + 5\beta^4 b + 3\beta^4 + 2\beta^3 b^3 + 8\beta^3 b^2 + 6\beta^3 b - 2\beta^3 + 2\beta^2 b^4 + 4\beta^2 b^3 + 2\beta^2 b^2 - 2\beta^2 b - 6\beta^2 + 2\beta b^3 - 4\beta b^2 - 7\beta b - \beta - 3b + 3$$

$$R_2^{coop} - R_2^{pp} = \frac{(a-c)^2\gamma}{(\beta+1)^2(b+1)(-\beta b^2+2\beta+2)^2}$$
$$\gamma = \beta^4 b^3 + \beta^4 * b^2 - \beta^4 b - \beta^4 + \beta^3 b^4 + 2\beta^3 b^3 - 2\beta^3 b + \beta^2 b^3 + \beta^2 b^2 + 2\beta^2 + 2\beta b^2 + 2\beta b + b - 1$$

In ***Figure 15***, the green line represents the exact combination of private level $\beta \in$*(0,1)*, and service differentiation $b \in$*(0,1)*, to satisfy $R_1^{coop} = R_1^{pp}$, and the red line represents that combination to make $R_2^{coop} = R_2^{pp}$. In other words, the function $R^{coop} - R^{pp} = 0,\ s.t. \beta \in (0,1)$ and $b \in (0,1)$ is solved to generate Figure 13. The spaces between the red and green lines refer to "unequal" areas, indicating either gaining or losing from the cooperation. The green plus "+" signs and green lines mark the area where $R_1^{coop} > R_1^{pp}$, showing the "willing to cooperate area" for port 1, while the green minus "-" sign surrounded by green lines shows the opposite meaning, $R_2^{coop} < R_2^{pp}$, or the "unwilling to cooperate area" for port 1. The red plus and minus signs are for port 2, following the same rule as for port 1.

So, the overlapping area with the same plus "+" sign surrounded by the same color lines is the area of feasible combinations to promote mutual cooperation since both ports can benefit from the cooperation by moving from previous price competition. The "willing to cooperate" area is marked with I and II, which can be found in both figures.

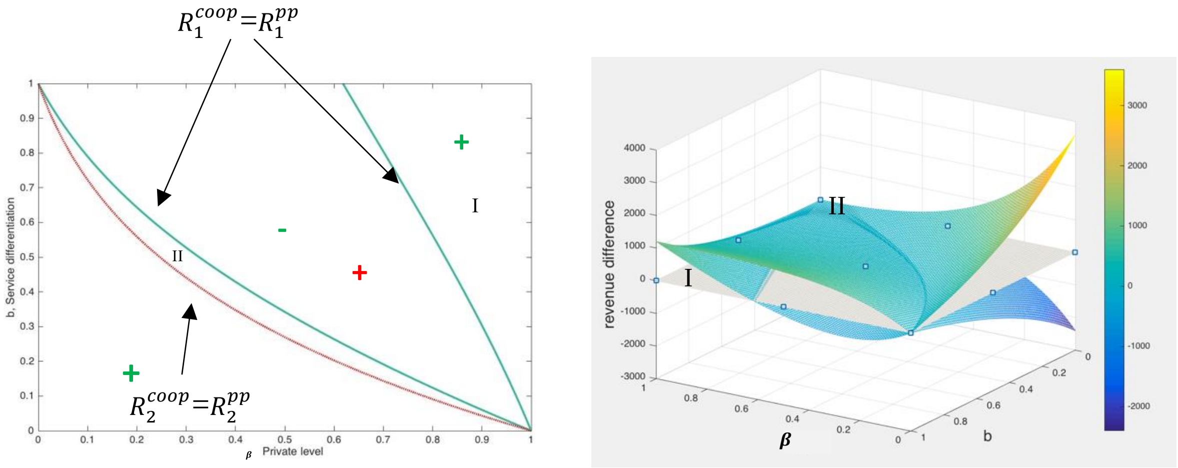


Figure 15 Outcome for p-p game, assuming a=100, c=2

Source: Authors` own elaboration

The area I (upper-right corner in the left ***Figure 15***, or the left side in the right) indicates that a relatively high private-oriented objective of port 1 ($\beta > 0.62$) will strongly promote cooperation from the p-p competition. Service differentiation plays a smaller role: a higher service similarity will help promote cooperation, although a higher service similarity will damage profitability. The slim area II (roughly along the diagonal line in the left, or the "valley way" in the right figure) shows "weakly balanced" positions where both ports are slightly better off from cooperation. The reason for having two feasible areas for cooperation is due to the combined goal of port 1: profit (private objective) and consumer surplus (public objective). The overall result by the two statuses can go either a public-objective-dominated way or profit-objective-dominated way with the possibility that the two dominated ways yield the same overall payoffs of port 1. In area I, the dominant private-concerned port 1 can easily cooperate with private port 2, preferring a higher service similarity (partly because higher service similarity will increase consumer surplus, which also contributes to the public objective of port 1). In area II, port 1 pays more attention to public-oriented objectives, which, combined with service differentiation, seriously limits the possibility of cooperation among various private levels.

- *Co-operation potential under the quantity-price (q-p) game*

The same methodology and signs are applied to the q-p game:

$$R_1^{coop} - R_1^{qp} = \frac{(a-c)^2 * \delta}{2(\beta+1)^2(b+1)(2\beta - 2\beta b^2 - b^2 + 2)^2}$$

$$\begin{aligned}\delta = {} & \beta^5 b^5 + \beta^5 b^4 - 2\beta^5 b^3 - 2\beta^5 b^2 + \beta^5 b + \beta^5 + 3\beta^5 b^5 + \beta^4 b^4 - 8\beta^4 b^3 - 4\beta^4 b^2 + 5\beta^4 b + 3\beta^4 + 3\beta^3 b^5 \\ & - 5\beta^3 b^4 - 8\beta^3 b^3 + 8\beta^3 b^2 + 6\beta^3 b - 2\beta^3 + \beta^2 b^5 - 3\beta^2 b^4 + 2\beta^2 b^3 + 10\beta^2 b^2 - 2\beta^2 b - 6\beta^2 \\ & + 6\beta b^3 - 2\beta b^2 - 7\beta b + \beta - 2b^3 - 2b^2 - 3b + 3\end{aligned}$$

$$R_2^{coop} - R_2^{qp} = \frac{-(a-c)^2 * \varepsilon}{(a1+1)^2 * (b+1) * (2 * a1 - 2 * a1 * b^2 - b^2 + 2)^2}$$

$$\begin{aligned}\varepsilon = {} & \beta^4 b^5 + \beta^4 b^4 - 2\beta^4 b^3 - 2\beta^4 b^2 + \beta^4 b + \beta^4 + 2\beta^3 b^5 - 4\beta^3 b^3 + 2\beta^3 b + \beta^2 b^5 + \beta^2 b^4 - \beta^2 b^3 + \beta^2 b^2 \\ & - 2\beta^2 + \beta b^4 + 2\beta b^3 - 2\beta b^2 - 2\beta b + b^3 - b^2 - b + 1\end{aligned}$$

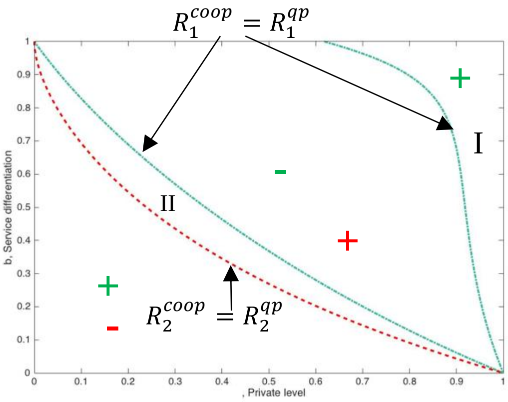


Figure 16 Outcome for q-p game, assuming a=100, c=2

Source: Authors` own elaboration

Area I is much smaller compared to the p-p game, which may imply that in adjusting the capacity/cargo volume strategy, port 1 will lose a certain possibility of facilitating cooperation. Area II is similar to the p-p game.

- *Co-operation potential under the price-quantity (p-q) game*

$$R_1^{coop} - R_1^{pq} = \frac{-(a-c)^2 * \epsilon}{2(\beta+1)^2(b+1)(2\beta - 2\beta b^2 - b^2 + 2)^2}$$

$$\begin{aligned}\epsilon = {} & \beta^5 b^3 + \beta^5 b^2 - \beta^5 b - \beta^5 + 2\beta^4 b^4 + 5\beta^4 b^3 + \beta^4 b^2 - 5\beta^4 b - 3\beta^4 + \beta^3 b^5 + 7\beta^3 b^4 + 4\beta^3 b^3 - 10\beta^3 b^2 \\ & - 6\beta^3 b + 2\beta^3 + 3\beta^2 b^5 + \beta^2 b^4 - 6\beta^2 b^3 - 8\beta^2 b^2 + 2\beta^2 b + 6\beta^2 + 3\beta b^5 - 3\beta b^4 - 9\beta b^3 \\ & + 5\beta b^2 + 7\beta b - \beta - b^4 - 3 * b^3 + 3 * b^2 + 3 * b - 3\end{aligned}$$

$$R_2^{coop} - R_2^{pq} = \frac{(a-c)^2 * \theta}{(\beta+1)^2(b+1)(2\beta - 2\beta b^2 - b^2 + 2)^2}$$

$$\begin{aligned}\theta = {} & \beta^4 b^3 + \beta^4 b^2 - \beta^4 b - \beta^4 + 2\beta^3 b^4 + 2\beta^3 b^3 - 2\beta^3 b^2 - 2\beta^3 b + \beta^2 b^5 - \beta^2 b^4 - \beta^2 b^3 - \beta^2 b^2 + 2\beta^2 + 2\beta b^5 \\ & - 3\beta b^4 - 4\beta b^3 + 4\beta b^2 + 2\beta b + b^5 - b^4 - 2b^3 + 2b^2 + b - 1\end{aligned}$$

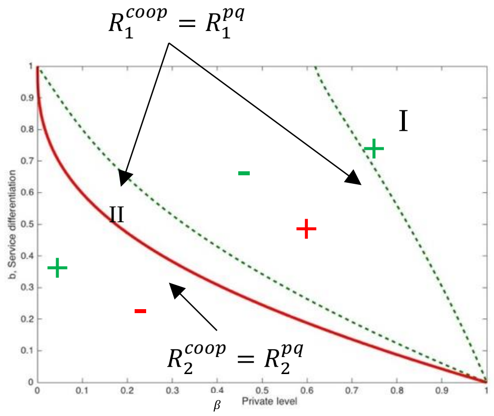


Figure 17 Outcome for p-q game, assuming a=100, c=2

Source: Authors` own elaboration

Area I is very similar to the p-p game status, but area II is slightly bigger and more concentrated in the "low private level and high service similarity" area.

- ***Limitations of the approach***

In this paper, we employ two most important assumptions: the linear demand function and the constant marginal cost for calculation simplification, but they can have significant (biased) implications for the results of the study.

A linear demand function implies a constant marginal cargo volume of demand in response to a marginal price change, irrespective of whether market prices are high or low. This characteristic of linear demand may not be in line with "a surprising degree of variation in elasticity estimates" (Merkel et al., 2022) observed in the shipping and port market. In this market, a change to demand is typically more sensitive to a change to price when prices are high, indicating a high price elasticity of demand due to the fierce competition between ports and the loose foot of transshipment cargo. Conversely, when prices are low, demand becomes less elastic because a minimum level of cargo flow is often considered a necessity for the economy. Consequently, a linear demand curve is inadequate for accurately representing market dynamics. In addition, the linear form of the demand curve may have a significant influence on the outcomes of Nash-Cournot-type models (Kahn, 1998), which may also distort the results. The constant marginal cost is employed in the model, as mentioned above, for calculation simplification, but obviously, it is not always constant, varying with the level of cargo volume, which may result from economies of scale, technologies, resources, and other factors. Although there is another cost structure, like quadratic cost structure, which is also commonly used in a mixed duopoly, it yields a similar result (i.e., welfare) as the constant cost structure (Matsumura 1998; Pal 1998; Tomaru and Kiyono 2010; Lin and Matsumura 2012; Haraguchi and Matsumura 2014). In general, when policy decisions are based on models with linear demand function and constant marginal cost assumptions, they may not address the actual economic challenges and opportunities, potentially leading to suboptimal policy outcomes.

3.5 Application in the scenario of the ports of Shenzhen and Hongkong

Applying the model to real-world cases presents a formidable challenge to faithfully replicate the theoretical game setting in practical scenarios. To provide a supplementary illustration, we have included an example that explores the dynamics of port competition between Hong Kong and

Shenzhen. It is worth noting that while this case offers valuable insights, it may not perfectly align with all the underlying assumptions of our theoretical game setting.

Shenzhen Port and Hongkong Port are spatially close with certain overlapping but not identical hinterland in the Pearl River delta (PRD).

Figure 18 Shenzhen Port and Hong Kong Port

Source: http://worldportsource.com

- Shenzhen Port

Shenzhen port consists of four major container terminal complexes, i.e., Yantian, Shekou and Chiwan/Mawan. The ownership structure of those 4 terminals can be found in the Table 12 (as in 2015). All the terminals are administrated by the Shenzhen harbor bureau (Port authority) and mainly "controlled" by it, since the shareholders of those terminals are mainly state-owned & municipal-owned (local) companies.

Table 12 Ownership structure of Shenzhen Port

	Yantian International Container Terminal	Shekou container terminals	Chiwan container terminal	Mawan container terminal
Shareholder information	19.8 bn state-own	CMHI: 80%	Chiwan Wharf Holdings Limited: 55%	CHMI: 70%
	Total 27.1 bn investment	**Modern terminal limited: 20% (subsidy of The Wharf (Holdings))***	**Kerry Logistics Network Limited:25%***	Chiwan Wharf Holdings Limited: 55%
			MTL chiwan: 20% (CHMI: 60%, **Modern terminal limited: 40%*)**	
Private level	26.94%	20%	33%	0%
Throughput, in million TEU	12.16	5.19	4.76	1.34

Aggregated private level	32.75% (between 0% and 100%)

*: Bold means the private entities.
Source: Various sources

- Hong Kong Port

Hong Kong`s container terminals are situated in the Kwai Chung-Tsing Yi basin. There are nine terminals operated by five different operators, namely Modern Terminals Ltd (MTL) (subsidiary of The Wharf (Holdings)), Hongkong International Terminals Ltd (HIT), COSCO-Hong Kong International Terminals Ltd (COSCO-HIT), Goodman DP World and Asia Container Terminals Ltd (ACT). The HK government is the lessor of land sites to the private terminal operating companies, and terminals are administrated by the maritime department (port authority). Neither the HK government nor the maritime department owns or operates container terminal facilities (Dong et al., 2002). All operators are private and profit-driven (although Cosco Port is state-owned, here we consider it as an investment company and profit-driven). Thus**, we consider the Port of Hongkong as a private (profit-driven) port, although it is under landlord mode.**

Table 13 Ownership structure of Hong Kong Port

Abb. name of port operator	**Full name**	**Shareholders**	**Terminal No.**
MTL	Modern terminal Ltd	Subsidiary of The Wharf (Holdings)	1, 2, 5, 9 South
DPI	Dubai Port International Terminals Ltd.	DP World	3
HIT	HONGKONG international terminals Ltd	HPH 66.5%, Portcapital Ltd 20%, China resource 10%	4, 6, 7, 8*, 9 North
COSCO	Cosco Pacific Ltd.	COSCO SHIPPING Ports Ltd.	8*
ACT	Asia Container Terminals Ltd		8 West

*: No. 8 terminal East is a joint-adventure between Cosco port and HIT
Source: Various sources

- Cost structure

In regard to the cost structure, it's important to acknowledge that specific cost data is unavailable. Furthermore, we have made an assumption that both ports employ similar technology. Therefore, in the case of Shenzhen and Hong Kong, we assume that the average cost per TEU (Twenty-Foot Equivalent Unit) for both ports is equivalent (c).

- Throughput (q) and service price (p)

We collected the two ports` throughput and service price (terminal handling charge) data as of 2015.
The throughput for SZ port is $q_1 = 23.45$ million TEU
The throughput for HK port is $q_2 = 20.07$ million TEU.

We assume that the terminal handling charge is an approximate index for the port service price. We collected the 20` dry container THC from the OOCL website: the average THC at HK for an inbound container is 2,019 HKD/TEU, and for an outbound container is 2,101 HKD/TEU.

The average THC at Shenzhen for inbound containers is 919 RMB/TEU and 886 RMB/TEU for outbound containers.
The average THC in HK is $p_2 = 1{,}813$ RMB/TEU (using the exchange rate between HKD and RMB)
The average THC in SZ is $p_1 = 903$ RMB/TEU.

- Results

In the scenario where the Port of Shenzhen and the Port of Hong Kong align with all the underlying assumptions, we can derive the following results.
The service differentiation parameter b can be determined as b=0.73.
The parameter a, representing the intercept of the demand curve, can be calculated as a=39,007.
It is noteworthy that we have assumed the private sector's share directly reflects the private level for simplification purposes, with a private sector share of 0.3275.

Based on our analysis of the cooperation potentials, we can find that:

- In Cournot competition (q-q game), they will not cooperate.

- In Bertrand competition (p-p game):

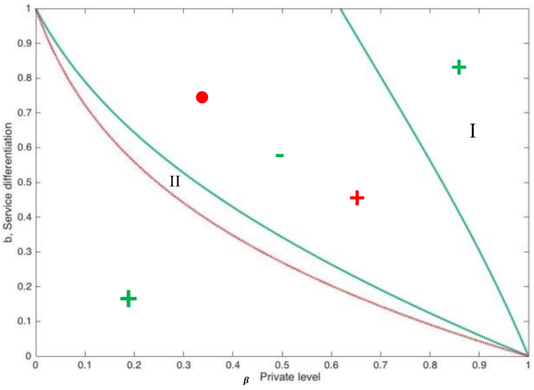


Figure 19 SZ and HK in Bertrand competition
Source: Authors` own elaboration

- In q-p game:

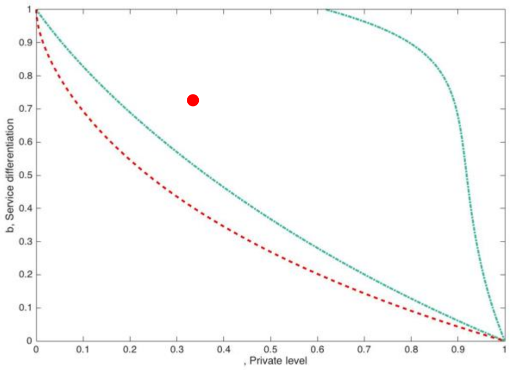


Figure 20 SZ and HK in q-p competition
Source: Authors` own elaboration

- In p-q game:

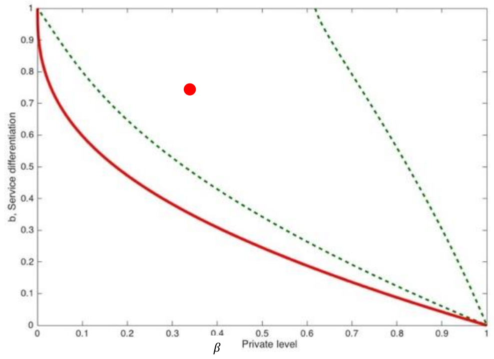


Figure 21 SZ and HK in p-q competition
Source: Authors` own elaboration

Consider the Bertrand competition, a scenario represented by the pricing competition (p-p game, see ***Figure 19***). In this context, the current position of Shenzhen and Hong Kong port denoted by the red dot, which corresponds to a specific combination of private level and service differentiation, may not be conducive to port integration. Should the government seek to promote integration from a market-oriented perspective, efforts should be directed towards shifting the red dot either towards the area marked as 'Triangle I' or the narrower region referred to as 'Area II”, where there are many different but possible pathways. **But again, we note that the usage/adaptation of the parameters of β and b should be evaluated carefully, which may completely change the results.**

3.6 Conclusions

In this paper, we used a differentiated mixed duopoly model to investigate the effects of public/private oriented objectives in various settings and find feasible combinations of private level and service differentiation level to promote cooperation from a previously (multiple) competing status. Besides, service quantity, service price, pure profit, and unweighted welfare are compared between the cooperation status and the competition status to reveal how potential cooperation will affect those parameters.

This paper adds value to extant literature in various ways. First, we made a more comprehensive analysis of both factors (i.e., privatization level and service differentiation level) using various settings of competition and cooperation by extending the study on the dominant strategy (price or quantity) in mixed duopoly by Matsumura et al. (2012). Second, we demonstrated that under capacity (Cournot) competition, both PAs will be reluctant to cooperate by forming a strategic alliance unless the partial public PA agrees to transfer certain profits to the private PA as compensation for joining the alliance. Third, we found that under p-p, q-p, and p-q competition, 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 in the same setting.

The outcomes of this paper can serve as useful inputs for ongoing public policy discussions on port competition and cooperation and a response to the trend of port integration. The paper provides an additional argument of service differentiation/similarity, private/public-oriented objectives, and feasible combinations of both factors to promote integration. In previous studies, a higher service similarity normally implies a “decrease in the service price and capacity” in competition and cooperation due to fierce homogeneous competition. In contrast, we found that under certain circumstances, increasing service similarity may lead to the opposite results.

However, an increasing service similarity will damage the profitability of both ports in all competition and cooperation scenarios, which is consistent with earlier studies. The effect of the public/private-oriented objective of the PA differs in the considered scenarios. In other words, our findings do not always support the notion that “port privatization will raise the price and lower the cargo volume”. Under Cournot competition, the capacity and service price of both ports is not affected by the private-oriented objective, which can only affect the partial public port`s revenue. Under Bertrend competition, q-p competition, and cooperation, an increasing level of private objective always increases service price but has a different influence on the cargo volume. It also benefits the private port since it will always transfer certain revenue from the partial public port to the private port. Under the cooperation scenario, service similarity compromises both ports` revenues and capacity but does not affect the joint price since the monopolistic alliance can control the price regardless of the service similarity/differentiation. An increasing private objective orientation of the PA can raise the service price and decrease the cargo volume, which is consistent with previous studies.

As for the feasible combinations in view of port cooperation, under Cournot competition (q-q), the private PA will not be willing to cooperate since cooperation is only in favor of the partial public PA, especially when the partial public PA has a high public concern and the ports’ services are non-substitutable. In addition, under Bertrand competition (p-p), Quantity-Price competition (q-p), and Price-Quantity competition (p-q), a PA with a highly private-oriented objective and the private PA are likely to cooperate, preferring more similar services between them. In contrast, the highly public-oriented PA will find it hard to cooperate with the private PA. The theoretical results are applied in the case of Shenzhen Port and Hongkong Port as a visual demonstration of their position in competition and possible pathways toward port integration (if the government is planning).

For the policy makers/government, this study`s result could be used to shape its policies related to the plan of port integrations from the competing scenarios and appears to align with the expectation of a trend toward port integration. For instance, the government can design an incentive mechanism that encourages cooperation between public and private entities for joining a strategic alliance by cross-subsidizing/compensating in certain scenarios. On the other hand, the two ports will merge naturally without the need for a government “push” in some other scenarios. In addition, the government should, to some extent, balance the aim in the triangle of maximizing the social welfare (throughput) and spillover effects of port integration and the concerns about monopoly (anti-trust policy)_. For the Port authority, understanding the conditions and scenarios (quantity or price or mixed competition) that favor cooperation is essential for effective partnership development, and it is also feasible to develop an agreement that offers profit-sharing arrangement or other compensation to make the integration more attractive (to solve the problem of shortage in port investments). For the port operators, this study can help the private port operators identify the opportunity for cooperation with the port authority to gain a better competitive position in the market. By applying the theoretical results in reality, the government/port authorities can map themselves in the port competition and use that map to find feasible pathways to foster a potential port integration.

The presented study faces some methodological simplifications and limitations. First, we assumed linear demand and cost functions for simplification, which may deviate from reality (which is further discussed at the end of Chapter 3.4). So, there is still a need to check the conclusions based on other suitable types of demand/cost functions, such as non-linear demand functions with conjectural variation and stochastic demand functions. Second, cooperation between two oligopolistic PAs may lead to a monopoly, which concerns the government. Finally, the inclusion of some practical issues in the models will help its robustness (e.g., global port operators operating in both ports, or the same municipal shares in both ports, etc.).

Appendix

Comparing the quantity, service price, profit, and welfare between the status of co-operation and competition

This section reveals how the potential cooperation influences the quantity, service price, pure profit, and un-weighted welfare of both ports, compared to previous competing status. In order to avoid the complex number solution, we use $f(\beta)$ to represent a certain function which contains complex numbers.

- Quantity:

$$q_1^{qq} < q_1^{coop}$$

$$q_1^{pp} > q_1^{coop}$$

$$q_1^{qp} > q_1^{coop}$$

$$q_1^{pq} - q_1^{coop} \gtreqless 0, if\ b \lesseqgtr -\frac{\sqrt{\beta^4 - 4\beta^3 + 12\beta + 8} + \beta^2}{2\beta + 2}$$

$$q_2^{qq} - q_2^{coop} \gtreqless 0, if\ b \gtreqless -\frac{2\beta - 2}{\beta + 1}$$

$$q_2^{pp} - q_2^{coop} \gtreqless 0, if\ b \gtreqless -\frac{(\beta - \sqrt{\frac{\beta(\beta^2 - 3\beta + 4)}{\beta + 1}})(\beta + 1)}{2\beta}$$

$$q_2^{qp} - q_2^{coop} \gtreqless 0, if\ b \lesseqgtr f(\beta)$$

$$q_2^{pq} - q_2^{coop} \gtreqless 0, if\ b \gtreqless -\frac{(\beta - \sqrt{\frac{\beta(\beta^2 - 3\beta + 4)}{\beta + 1}})(\beta + 1)}{2\beta}$$

After moving into cooperation status, the service quantity provided by both ports change divergently.

- Service price (assuming a=100, c=2):

$$p_1^{coop} - p_1^{qq} \gtreqless 0, if\ b \lesseqgtr -\frac{\sqrt{\beta^4 - 4\beta^3 + 12\beta + 8} + \beta^2}{2\beta + 2}$$

$$p_1^{coop} - p_1^{pp} > 0$$

$$p_1^{coop} - p_1^{qp} > 0$$

$$p_1^{coop} - p_1^{pq} > 0$$

$$p_2^{coop} - p_2^{qq} < 0$$

$$p_2^{coop} - p_2^{pp} \gtreqless 0, if\ b \gtreqless \frac{(\sqrt{\frac{-4\beta^2 + 5\beta + 1}{\beta + 1}} - 1)(\beta + 1)}{2\beta}$$

$$p_2^{coop} - p_2^{qp} \gtreqless 0, if\ b \gtreqless \frac{(\sqrt{\frac{-4\beta^3 - 4\beta^2 + \beta + 1}{\beta + 1}} - 1)(\beta + 1)}{2\beta^2}$$

$$p_2^{coop} - p_2^{pq} < 0$$

For partial public port 1, cooperation will raise its service price in most cases. However, for the private port 2, cooperation does not guarantee a higher price charged.

- Pure profits, profit=(price-cost) *quantity. (Assuming a=100, c=2)

$$profit_1^{qq} < profit_1^{coop}$$
$$profit_1^{pp} < profit_1^{coop}$$
$$profit_1^{qp} < profit1_{coop}$$
$$profit_1^{pq} < profit1_{coop}$$

$$profit_2^{qq} < profit_2^{coop}$$
$$profit_2^{pp} - profit_2^{coop} \gtreqless 0, if\ b \gtreqless f(\beta)\text{`}$$
$$profit2_{qp} - profit_2^{coop} \gtreqless 0, if\ b \gtreqless f(\beta)\text{``}$$
$$profit2_{pq} - profit_2^{coop} \gtreqless 0, if\ b \gtreqless f(\beta)\text{```}$$

For partial port 1, it always benefits from cooperation in all the scenarios, while private port 2 will face a loss or a gain, depending on the relation between service differentiation and the private objective level.

- (un-weighted) Welfare

$$welfare^{qq} - welfare^{coop} \gtreqless 0, if\ b \gtreqless -\frac{12\beta + 6\beta^2 - 2\sqrt{-\beta^4 - 4\beta^3 - 14\beta^2 - 20\beta + 55} - 10}{5\beta^2 + 10\beta + 5}$$
$$welfare^{pp} - welfare^{coop} \gtreqless 0, if\ b \gtreqless f(a1)\text{````}$$
$$welfare^{qp} - welfare^{coop} \gtreqless 0, if\ b \gtreqless f(a1)\text{`````}$$
$$welfare^{pq} - welfare^{coop} \gtreqless 0, if\ b \gtreqless f(a1)\text{``````}$$

The cooperation cannot guarantee a better off on all un-weighted welfare, compared to that in previous competing status, and it depends on the relationship between service differentiation and the private objective level.

References

Anderson, C.M., Park, Y.A., Chang, Y.T., Yang, C.H., Lee, T.W. and Luo, M., 2008. A game-theoretic analysis of competition among container port hubs: the case of Busan and Shanghai. *Maritime Policy & Management*, 35(1), pp.5-26.

Brooks, M.R., 2004. The governance structure of ports. *Review of Network Economics*, 3(2).

Brooks, M.R., 2006. Issues in measuring port devolution program performance: a managerial perspective. *Research in Transportation Economics*, 17, pp.599-629.

Cetin, C.K. and Cerit, A.G., 2010. Organizational effectiveness at seaports: a systems approach. *Maritime Policy & Management*, 37(3), pp.195-219.

Cheng, J. and Yang, Z., 2017. The equilibria of port investment in a multi-port region in China. *Transportation Research Part E: Logistics and Transportation Review*, *108*, pp.36-51.

Chlomoudis, C.I. and Pallis, A.A., 2004, June. Port governance and the smart port authority: key issues for the reinforcement of quality services in European ports. In WORLD CONFERENCE ON TRANSPORT RESEARCH (Vol. 10).

Cullinane, K. and Song, D.W., 2002. Port privatization policy and practice. *Transport Reviews*, 22(1), pp.55-75.

Cullinane, K., Ji, P. and Wang, T.F., 2005. The relationship between privatization and DEA estimates of efficiency in the container port industry. *Journal of economics and business*, 57(5), pp.433-462.

Cullinane, K., Teng, Y. and Wang, T.F., 2005. Port competition between Shanghai and Ningbo. *Maritime Policy & Management*, 32(4), pp.331-346.

Czerny, A., Höffler, F. and Mun, S.I., 2014. Hub port competition and welfare effects of strategic privatization. *Economics of Transportation*, 3(3), pp.211-220.

Czerny, A., Höffler, F. and Mun, S.I., 2014. Hub port competition and welfare effects of strategic privatization. *Economics of Transportation*, 3(3), pp.211-220.

De Borger, B., Proost, S. and Van Dender, K., 2008. Private port pricing and public investment in port and hinterland capacity. *Journal of Transport Economics and Policy* (JTEP), 42(3), pp.527-561.

De Langen, P.W. and Heij, C., 2014. Corporatisation and performance: a literature review and an analysis of the performance effects of the corporatisation of port of Rotterdam authority. *Transport Reviews, 34*(3), pp.396-414.

De Langen, P.W. and Nijdam, M.H., 2009. A Best Practice in Cross-border Port Cooperation: Copenhagen Malmö Port. *Ports in Proximity: Competition and Coordination among Adjacent Seaports*, pp.163-174.

De Langen, P.W., 2007. Port competition and selection in contestable hinterlands; the case of Austria. *European Journal of Transport and Infrastructure Research,* 7(1), pp.1-14.

De Langen, P.W., 2008. Ensuring Hinterland Access The Role of Port Authorities.

Dong, G., Zheng, S. and Lee, P.T.W., 2018. The effects of regional port integration: The case of Ningbo-Zhoushan Port. *Transportation Research Part E: Logistics and Transportation Review*, *120*, pp.1-15.

Donselaar, P.W.V. and Kolkman, J., 2010. Societal costs and benefits of cooperation between port authorities. *Maritime Policy & Management*, 37(3), pp.271-284.

Dooms, M., van der Lugt, L. and de Langen, P.W., 2013. International strategies of port authorities: The case of the Port of Rotterdam Authority. *Research in Transportation Business & Management*, 8, pp.148-157.

Ferrari, C., Tei, A. and Merk, O., 2015. The Governance and Regulation of Ports: the case of Italy.

Haezendonck., E. and T. Notteboom, 2002, The competitive advantage of seaports. "Port Competitiveness: An Economic and Legal Analysis of the Factors Determining the Competitiveness of Seaports", pp. 67-88. Antwerp: De Boeck.

Haraguchi, J. and Matsumura, T., 2014. Price versus quantity in a mixed duopoly with foreign penetration. *Research in Economics*, *68*(4), pp.338-353.

Haralambides, H.E., Cariou, P. and Benacchio, M., 2002. Costs, benefits and pricing of dedicated container terminals. *International Journal of Maritime Economics*, 4(1), pp.21-34.

Heaver, T., Meersman, H. and Van de Voorde, E., 2001. Co-operation and competition in international container transport: strategies for ports. *Maritime Policy & Management*, 28(3), pp.293-305.

Heaver, T., Meersman, H., Moglia, F. and Van de Voorde, E., 2000. Do mergers and alliances influence European shipping and port competition? *Maritime Policy & Management*, 27(4), pp.363-373.

Hidalgo-Gallego, S., Núñez-Sánchez, R. and Coto-Millán, P., 2022. Port allocative efficiency and port devolution: a study for the Spanish port authorities (1992-2016). *Maritime Policy & Management*, *49*(1), pp.39-61.

Huo, W., Zhang, W. and Chen, P.S.L., 2018. Recent development of Chinese port cooperation strategies. *Research in transportation business & management*, *26*, pp.67-75.

Inoue, S., 2018. Realities and challenges of port alliance in Japan—Ports of Kobe and Osaka. *Research in Transportation Business & Management*, *26*, pp.45-55.

Ishii, M., Lee, P.T.W., Tezuka, K. and Chang, Y.T., 2013. A game theoretical analysis of port competition. *Transportation Research Part E: Logistics and Transportation Review*, 49(1), pp.92-106.

Kahn, E.P., 1998. Numerical techniques for analyzing market power in electricity. *The Electricity Journal*, *11*(6), pp.34-43.

Kaselimi, E.N., Notteboom, T.E. and De Borger, B., 2011. A game theoretical approach to competition between multi-user terminals: the impact of dedicated terminals. *Maritime Policy & Management*, 38(4), pp.395-414.

Lam and Yap (2006) A measurement and comparison of cost competitiveness of container ports in Southeast Asia, *Transportation*, *33*, 641-654

Lim, Y. T., 2008, Building Intra-regional Port Alliance in Northeast Asia, *Space and Environment*, Vol. 32, pp. 3-5.

Lin, M.H. and Matsumura, T., 2012. Presence of foreign investors in privatized firms and privatization policy. *Journal of Economics*, *107*, pp.71-80.

Luo, M., Liu, L. and Gao, F., 2012. Post-entry container port capacity expansion. *Transportation Research Part B: Methodological*, 46(1), pp.120-138.

Matsumura, T. and Ogawa, A., 2012. Price versus quantity in a mixed duopoly. *Economics Letters*, 116(2), pp.174-177.

Matsumura, T., 1998. Partial privatization in mixed duopoly. *Journal of Public Economics*, 70(3), pp.473-483.

Matsushima, N. and Takauchi, K., 2014. Port privatization in an international oligopoly. *Transportation Research Part B: Methodological*, 67, pp.382-397.

Merkel, A., Johansson, M., Lindgren, S. and Vierth, I., 2022. How (in) elastic is the demand for short-sea shipping? A review of elasticities and application of different models to Swedish freight flows. *Transport Reviews*, *42*(4), pp.551-571.

Ng, A.K. and Pallis, A.A., 2010. Port governance reforms in diversified institutional frameworks: generic solutions, implementation asymmetries. *Environment and Planning A*, *42*(9), pp.2147-2167.

Ng, K.Y.A., 2006. Theory and structure of port competition: a case study of container transshipment in North Europe (Doctoral dissertation, University of Oxford).

Notteboom, T. and Yang, Z., 2017. Port governance in China since 2004: Institutional layering and the growing impact of broader policies. *Research in transportation business & management, 22*, pp.184-200.

Notteboom, T. and Yap, W.Y., 2012. Port competition and competitiveness. *The Blackwell Companion to Maritime Economics*, pp.549-570.

Notteboom, T.E. and Rodrigue, J.P., 2005. Port regionalization: towards a new phase in port development. *Maritime Policy & Management*, 32(3), pp.297-313.

Notteboom, T.E. and Winkelmans, W., 2001. Structural changes in logistics: how will port authorities face the challenge?. *Maritime Policy & Management*, 28(1), pp.71-89.

Notteboom, T.E., 2009. Complementarity and substitutability among adjacent gateway ports. *Environment and Planning A*, *41*(3), pp.743-762.

Notteboom, T.E., Parola, F., Satta, G. and Pallis, A.A., 2017. The relationship between port choice and terminal involvement of alliance members in container shipping. *Journal of Transport Geography*, 64, pp.158-173.

Pal, D., 1998. Endogenous timing in a mixed oligopoly. *Economics Letters*, *61*(2), pp.181-185.

Pallis, A.A. and Syriopoulos, T., 2007. Port governance models: Financial evaluation of Greek port restructuring. *Transport Policy*, *14*(3), pp.232-246.

Pollitt, C. and Bouckaert, G., 2003. Evaluating public management reforms: an international perspective. *Evaluation in Public-Sector Reform. Concepts and Practice in International Perspective. Cheltenham*, pp.12-35.

Ryoo, D.K., 2011. A Conceptual Framework of Port Cooperation. *Journal of Korean navigation and port research*, 35(7), pp.581-588.

Saeed, N. and Larsen, O.I., 2010. An application of cooperative game among container terminals of one port. *European Journal of Operational Research*, 203(2), pp.393-403.

Slack, B., 1985. Containerization, inter-port competition, and port selection. *Maritime policy and management*, 12(4), pp.293-303.

Slack, B., Comtois, C. and McCalla, R., 2002. Strategic alliances in the container shipping industry: a global perspective. *Maritime Policy & Management*, 29(1), pp.65-76.

Song, D.W., 2002. Regional container port competition and co-operation: the case of Hong Kong and South China. *Journal of Transport Geography*, 10(2), pp.99-110.

Song, D.W., 2003. Port co-opetition in concept and practice. *Maritime Policy & Management*, 30(1), pp.29-44.

Song, D.W., Cheon S. and Pire C., 2015. Does size matter for port coopetition strategy? Concept, motivation and implication. *International Journal of Logistics Research and Applications, Vol. 18*, Iss. 3.

Soppé, M., Parola, F. and Frémont, A., 2009. Emerging inter-industry partnerships between shipping lines and stevedores: from rivalry to cooperation? *Journal of Transport Geography*, 17(1), pp.10-20.

Tian, X., Liu, L. and Wang, S., 2015. Evolving competition between Hong Kong and Shenzhen ports. *Maritime Policy & Management*, *42*(8), pp.729-745.

Tomaru, Y. and Kiyono, K., 2010. Endogenous timing in mixed duopoly with increasing marginal costs. *Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft*, pp.591-613.

Tongzon, J. and Heng, W., 2005. Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). *Transportation Research Part A: Policy and Practice*, 39(5), pp.405-424.

Van der Lugt, L. and De Langen, P.W., 2007, July. Port authority strategy: beyond the landlord–a conceptual approach. In *Proceedings of the 2007 IAME Conference*.

van der Lugt, L.M., de Langen, P.W. and Hagdorn, L., 2016. Strategic beliefs of port authorities. *Transport Reviews*, pp.1-30.

Van der Lugt, L.M., Rodrigues, S.B. and Van den Berg, R., 2014. Co-evolution of the strategic reorientation of port actors: insights from the Port of Rotterdam and the Port of Barcelona. *Journal of Transport Geography*, 41, pp.197-209.

Veldman, S.J. and Bückmann, E.H., 2003. A model on container port competition: an application for the West European container hub-ports. *Maritime Economics & Logistics*, 5(1), pp.3-22.

Verhoeven, P., 2010. A review of port authority functions: towards a renaissance?. *Maritime Policy & Management*, 37(3), pp.247-270.

Wan, Y., Basso, L.J. and Zhang, A., 2016. Strategic investments in accessibility under port competition and inter-regional coordination. *Transportation Research Part B: Methodological*, 93, pp.102-125.

Wang, K., Ng, A.K., Lam, J.S.L. and Fu, X., 2012. Cooperation or competition? Factors and conditions affecting regional port governance in South China. *Maritime Economics & Logistics*, 14(3), pp.386-408.

World Bank, World Bank Port Reform Toolkit, http://siteresources.worldbank.org/INTPRAL/Resources/338897-1164990391106/00_TOOLKIT_FM_Vol1.pdf

Xiao, Y., Ng, A.K., Yang, H. and Fu, X., 2012. An analysis of the dynamics of ownership, capacity investments and pricing structure of ports. *Transport Reviews*, *32*(5), pp.629-652.

Yap, W.Y. and Lam, J.S., 2006. Competition dynamics between container ports in East Asia. *Transportation Research Part A: Policy and Practice*, *40*(1), pp.35-51.

Yip, T.L., Liu, J.J., Fu, X. and Feng, J., 2014. Modeling the effects of competition on seaport terminal awarding. *Transport Policy*, 35, pp.341-349.

Yuen, A.C.L., Zhang, A. and Cheung, W., 2013. Foreign participation and competition: A way to improve the container port efficiency in China? *Transportation Research Part A: Policy and Practice*, 49, pp.220-231.

Zhuang, W., Luo, M. and Fu, X., 2014. A game theory analysis of port specialization—implications to the Chinese port industry. *Maritime Policy & Management*, *41*(3), pp.268-287.

Chapter 4 Vertical integration of shipping lines in port competition and expansion

Abstract

This study mainly investigates the effects of vertical integration in the form of joint investment on new capacity between a shipping line and a landlord port by comparing the equilibrium of integrated and non-integrated scenarios in the context of port competition (mixed duopoly). The results indicate that vertical integration can be an important source of synergy for the maritime industry and help the port and shipping line to gain competitiveness against their rivals.

Keywords: *Vertical integration, new capacity investment, port competition, port privatization*

4.1 Introduction

The shipping industry has experienced significant changes in recent years, demonstrating a notable trend in which shipping lines are increasingly involved in port management and terminal operation (Drewry 2017), sometimes part of broader vertical integration strategies which can also involve inland logistics, air freight, and other activities (see Paridaens and Notteboom, 2022 for an overview of logistics integration strategies of Maersk, MSC and CMA CGM). Those shipping lines started to vertically integrate with ports, such as acquiring equity stakes in terminal operating companies or directly managing terminal facilities for exploiting dedicated service (Slack, 1993; Haralambides et al., 2002; Soppé et al., 2009). Some of the vertical integrations result in dedicated terminals, which only handle their own containers. In recent times, the semi-dedicated formula (i.e., selling spare capacity to third-party customers, which are often partners in shipping alliances) became more and more common in order to achieve a higher degree of utilization of the facility, thus reducing management costs (Notteboom et al., 2017).

The reason behind the trend of carriers’ vertical integration involving port terminals is well studied and considered mutually beneficial: with the increasing size of ships, acquiring/controlling stakes in container facilities can help shipping lines avoid costs related to inefficiency and delays in terminal operations (Imai et al., 2006). Vertical integration will also cut port costs, such as terminal handling costs, by gaining more bargaining power against stevedores (Rodrigue and Notteboom, 2010). The involvement of shipping companies in terminal activities may be directed to pursue economies of scope or service quality and reliability by creating a port network consistent with the needs of their clients, i.e., the shippers (De Souza et al., 2003). Furthermore, along with the carrier's perspective, a closer relationship with a terminal operator via equity partnerships in container terminal projects is expected to effectively improve carriers' business networks (Soppé et al., 2009; Parola et al., 2014).

The most commonly used method for vertical integration is allowing the port authority to lease part of assets/facilities to shipping lines by reaching a mutual agreement or concession so that shipping lines can take over part or full management of a port terminal. Most modern container terminals follow the concession agreement model, often with joint ventures formed with a mixture of financial investors, shipping lines, terminal operators, construction companies, and local interests (Yip et al., 2014). In practice, several deep-sea companies have their own terminal operating companies, such as Maersk (APM Terminals), MSC (majority shareholding in Terminal Investment Limited), CMA CGM (majority shareholding in Terminal Link) and COSCO (COSCO shipping ports), and those hybrid companies adapt their strategies toward terminal operations, which welcome all third-party carriers to generate a large part of profits (Notteboom et al., 2017). However, some other shipping lines, such as Evergreen, Yang Ming, NYK, and MOL, differ in the strategy of vertical integration by offering public service in their own "home court" (i.e., Japan, ROC) but only operate dedicated terminals as gateways in other regions (Zhu et al., 2019).

Meanwhile, the formation of shipping line alliances and market consolidation, with the help of enlarging the size of ships, have led to more fierce port competition, which accelerates vertical integration. Larger but fewer container ships are deployed by the three existing giant shipping alliances in the key routes between continents to cut the unit cost, benefiting from the economies of scale. This market/route concertation is challenging the ports in all aspects. So, ports have to actively adapt themselves to these new trends, such as investing in new infrastructure/ICT and implementing a new port governance system, etc. However, port investment has a long-term payback and high capital cost (Tongzon and Heng, 2005), which potentially drives cooperation between ports and shipping lines. Shipping lines can provide more reliable service to their customers, and ports can get access to external funds for port expansion in order to maintain their competitiveness, forming a win-win situation.

The ongoing port privatization is adding more complexity to vertical integration. In typical public/tool or private ports, the whole port is performing as one with a clear and unified ownership structure, mainly focusing on either higher throughput or higher profits (ROI). But in the case of a landlord port, as a mixture of state/municipal interests and private company interests, the port authority seeks a balance between promoting sustainable development (e.g., by including throughput guarantees in the concession agreement, attracting investments, profits, etc.) and making the most efficient use of the available land (i.e., related to the agreements with port operators about the profit allocation through the concession) (Cui and Notteboom, 2017). So, the differentiated objectives between public port authorities and private port operators in the landlord port will add more uncertainty to the decision of vertical integration. For instance, the bidding for the concession of Piraeus in Greece by COSCO was doubted by the local Greek government and other European stakeholders, which still shows that there is no consensus on the effects of the best and standard approach to such an industrial trend among the maritime industry and government policymakers (Zhu et al., 2019; Yang et al., 2022).

So, it is interesting to investigate how vertical integration, such as through a new port expansion between a shipping line and a landlord port, affects individual actors and related parameters in the context of different settings of port competition (mixed duopoly game, partial public port vs. private port).

The remainder of this paper is organized as follows: Section 4.2 is a literature review on vertical integration in general with port privatization and competition. Then, in Section 4.3, we present an economic model of vertical integration between a shipping line and a landlord port in the context of port competition and also make a comparison of the equilibrium with or without integration. Section 4.4 presents a numeric example of the result of Section 4.3. The discussion and conclusions are presented in section 4.5.

4.2 Literature review

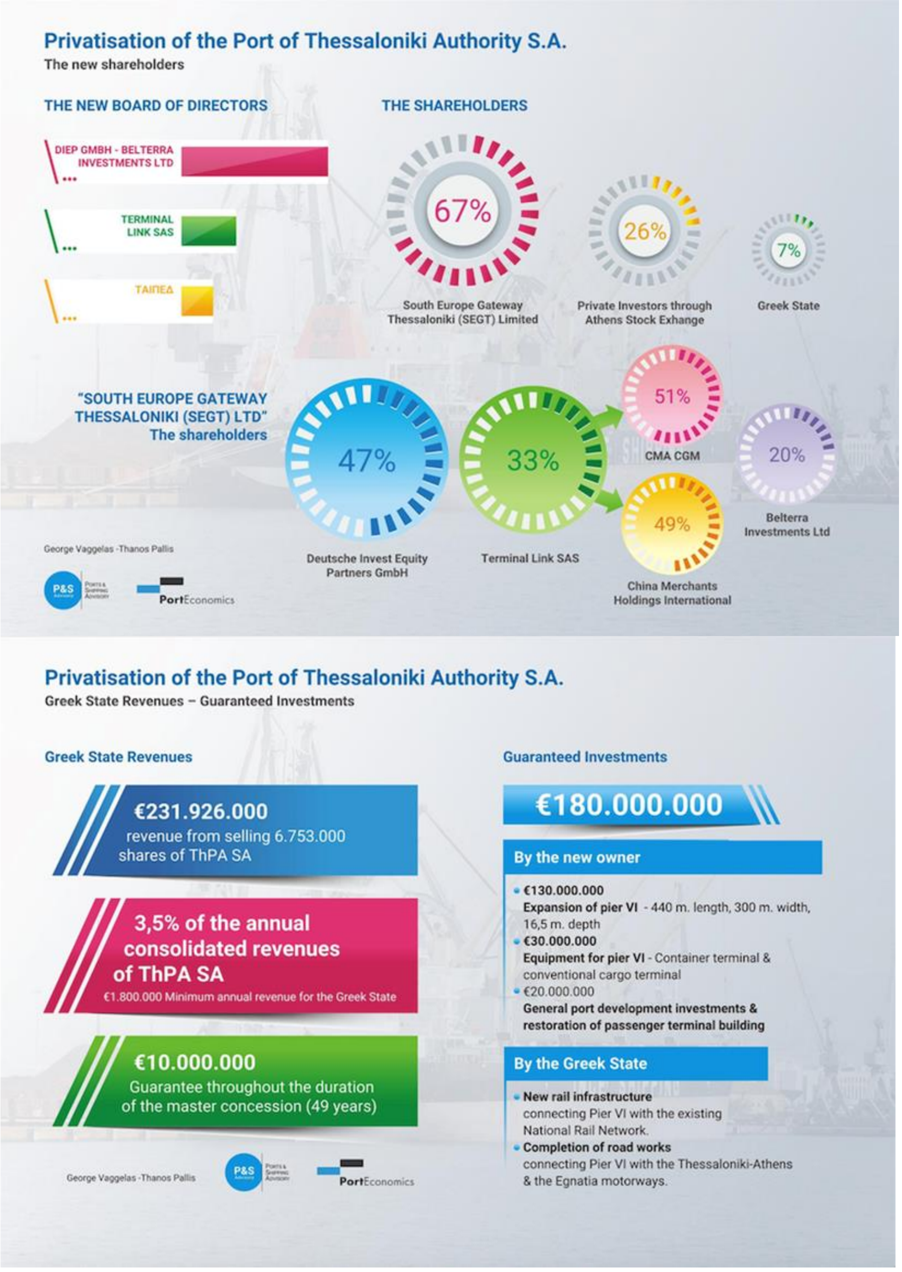
Vertical integration, in general, is an enduring economic topic, mainly because it is related to antitrust policy. Studies have shown that vertical integration can help integrated companies gain more market power, monopoly profit, and bargaining power and eliminate double marginalization if upstream and downstream work well (Spengler, 1950). On the other side, Riordan (1998) shows that vertical integration can raise rivals` costs and hence may be anti-competitive. E Gal-Or (1992) found that duopolistic upstream firms may have less incentive to vertically integrate compared with a monopolistic upstream firm, and the consumer surplus is definitely higher if firms find it optimal to integrate, but industry profit might decline. Chipty (2001) also found a similar result that vertical integration does not harm, and may actually benefit, consumers because of the associated efficiency gains. So overall, vertical integration may become a prisoner`s dilemma, depending on the market structure.

In the maritime industry, cooperation within or between shipping lines, port authorities, and port operators is very common (Heaver et al., 2001). Although, during the period 2014–2017, strong horizontal integration among shipping lines (formation of shipping alliance) moves overshadowed the few attempts to vertically integrate, and the dominant business strategy became saving costs, chasing economies of scale via larger ships and industry consolidation through an increase in market share, logistics integration (including vertical integration) starts attracting attention among those participants due to the disturbance and disruption of the maritime supply chain during the outbreak of COVID-19 (Paridaens et al., 2022, ITF, 2022). As for ports, port cooperation is a natural response to the increasing competitive pressures, including vertical cooperation with carriers/ports and horizontal cooperation with other ports, and the types of port cooperation are significantly diverse.

Vertical integration between a shipping line and a port terminal is a typical form of cooperation. From a carrier`s perspective, Midoro et al. (2005) found that investments by carriers can serve shippers better by increasing efficiency and reliability and cutting costs. Notteboom et al. (2012) argued that such integration could help carriers reduce risks. From the port perspective, Van de Voorde et al. (2010) pointed out this integration will help the port meet the growing infrastructure requirement for terminals due to the enlarging size of mega ships, and Rodrigue and Notteboom (2009) argued the integration could further help the public port authority obtain more investment/expansions to meet the ever-growing traffic volume, infrastructure requirement, and financial risks. From the port operator`s perspective, the integration can expand their business scale and strengthen their bargaining power against shipping lines (Lee et al., 2014). Besides, in more recent years, some shipping lines, such as Maersk and CMA CGM, have developed far-reaching logistics integration strategies by also extending their reach into logistics, e-commerce, air freight, and other related activities (Paridaens and Notteboom, 2022) compared to the slow pace of liberalization of European railway market back in the 2000s.

The dedicated or semi-dedicated terminal is a very popular form of vertical integration in the maritime industry due to the increasing gap between the objectives of the ports and shipping lines. Haralambides et al. (2002) provide a detailed discussion and analysis of the benefits of dedicated terminals, including offering flexibility, reliability, short turnaround times, and efficiency of the global supply chain. Reynaerts (2010) and Van Reeven (2010) both analyze how the dedicated terminals affect the different actors in the port industry: Reynaerts (2010) empirically studies the merger between two terminal operators using a Bertrand competition model to assess its impact on profits and social welfare, and Van Reeven (2010) uses a horizontal product differentiation model in which two ports compete for cargo trans-shipments that the landlord port governance scheme without intra-port competition is a Nash equilibrium yielding the highest profits for the port industry and the highest prices for its customers. Kaselimi et al. (2011) analyze a model of competition between non-dedicated terminals using a typical Hoteling specification to evaluate the impact of non-dedicated and dedicated terminals. Álvarez et al. (2013) extend the analysis of Kaselimi et al. (2011) by adding more scenarios and find that carriers should operate their own terminal non-exclusively for higher profits. De Borger et al. (2011) model the vertical integration between terminal operators and transport firms and argue that it is beneficial for the government to not only promote competition between downstream firms but also approve the vertical integration in the logistics chain. Guo and Wang (2009) considered the competition and cooperation problem between the port and shipping company and used a game theory approach to study the optimal input of effort costs and pricing between the port and shipping company. Asgari et al. (2013) investigated the competition and cooperation strategies of two competing ports and their shipping lines and found that, in the long run, the port should form strategic alliances with shipping lines and other ports to gain more market share and profits. Zhu et al. (2019) developed an analytical model to study the effect of vertical integration between a landlord port and a shipping line among competing shipping lines, mainly focusing on the investment of shipping lines into the new expansion capacity. Jiang et al. (2021) extended the study of Zhu et al. (2019) from a single landlord port system to a two-port system, with some modifications of the assumptions, and found that the initial port capacity will affect the relative scale of the capacity investment. Besides, Franc and Van der Horst (2010) reveal the motivations behind the integration by the shipping line and terminal operators by making use of insights from Transaction Cost Economics (TCE). They demonstrate that SLs develop inland transport services and inland terminals especially to cope with unreliable services, and terminal operation companies (TOCs) try to deal with the scarcity of space in ports and terminals as well as the lack of coordination with transport service providers. It is echoed by the trend that the semi-dedicated formula (i.e., selling spare capacity to third-party customers, which are often partners in the shipping alliance) became more common in order to achieve a higher degree of facility utilization, thus reducing management costs (Notteboom et al., 2017). From the Perspective of TCE, this involvement of carriers in the terminal operation/expansion/logistics chain can be defined as vertical quasi-integration (Zaheer et al., 1995). It allows for the benefits of collaboration and specialization while maintaining a level of autonomy and flexibility that may not be present in full internalization (Blois, 1972) compared to internalization ("full integration" in TCE).

Meanwhile, with the trend of port reform (privatization), there has been a notable decrease in the number of state-owned terminal facilities, accompanied by a rise in private investment in container terminals as a means to overcome shortages in port infrastructure (Álvarez-SanJaime et al., 2013), introduce market-driven efficiency and enhance overall performance. It entails the transfer of administration, ownership, and operation from the previous state-owned sector to private entities (Cullinane and Song, 2002). In practice, the form of port privatization can vary widely, and several prominent modes have been implemented around the world, including landlord-Latin mode (France, Italy, Spain), landlord-Hanseatic mode (Belgium, Germany, Netherlands), and fully privatized model (UK). The prevalent method to privatize the port is done by the concession/lease agreement. The government grants a concession to a private sector, allowing it to operate, develop, and manage port facilities/terminals with certain guarantees like throughput/revenue for a certain term. The figure illustrates the details of a concession agreement in the privatization of the port of Thessaloniki Authority S.A. (Greece) in 2018, including the share distribution among the public and private sectors (**CMA-CGM shipping line is included**), as well as the nuanced delineation of responsibilities on both sides, thus exemplifying the multi-faceted nature of the agreement. Besides, there are plenty of qualitative and quantitative studies regarding port privatization, whether related to vertical integration or not. Baltazar et al. (2001), Midoro et al. (2005), and Czerny et al. (2013) all argued that privatizing or corporatizing public ports is a policy option to raise the competitive position of their ports, and Cullinane et al. (2005), Tongzon et al. (2005), Pagano et al. (2013) found port privatization beneficial by examining cost-effectiveness and technical efficiency. Xiao et al. (2012) and Matsushima et al. (2014) all investigated the effects of a port`s ownership structure on port charges, investment, profits, and welfare in the context of competition using the game theory approach. In practice, ***Figure 23*** shows the global distribution of APM Terminals (a subsidiary of A.P. Moller-Maersk **or a sister company of Maersk line**), reflecting not only port privatization but also vertical integration between the shipping line and ports/terminals.



Privatisation of the Port of Thessaloniki Authority S.A.

The new shareholders

THE NEW BOARD OF DIRECTORS

- DIEP GMBH - BELTERRA INVESTMENTS LTD ...
- TERMINAL LINK SAS ...
- ΤΑΙΠΕΔ ...

THE SHAREHOLDERS

"SOUTH EUROPE GATEWAY THESSALONIKI (SEGT) LTD"
The shareholders

George Vaggelas -Thanos Pallis

Privatisation of the Port of Thessaloniki Authority S.A.

Greek State Revenues – Guaranteed Investments

Greek State Revenues

€231.926.000
revenue from selling 6.753.000 shares of ThPA SA

3,5% of the annual consolidated revenues of ThPA SA
€1.800.000 Minimum annual revenue for the Greek State

€10.000.000
Guarantee throughout the duration of the master concession (49 years)

Guaranteed Investments

€180.000.000

By the new owner

- **€130.000.000**
  Expansion of pier VI - 440 m. length, 300 m. width, 16,5 m. depth
- **€30.000.000**
  Equipment for pier VI - Container terminal & conventional cargo terminal
- €20.000.000
  General port development investments & restoration of passenger terminal building

By the Greek State

- **New rail infrastructure**
  connecting Pier VI with the existing National Rail Network.
- **Completion of road works**
  connecting Pier VI with the Thessaloniki-Athens & the Egnatia motorways.

George Vaggelas -Thanos Pallis

Figure 22 Privatization of the port of Thessaloniki Authority S.A.

Source: Porteconomics.eu

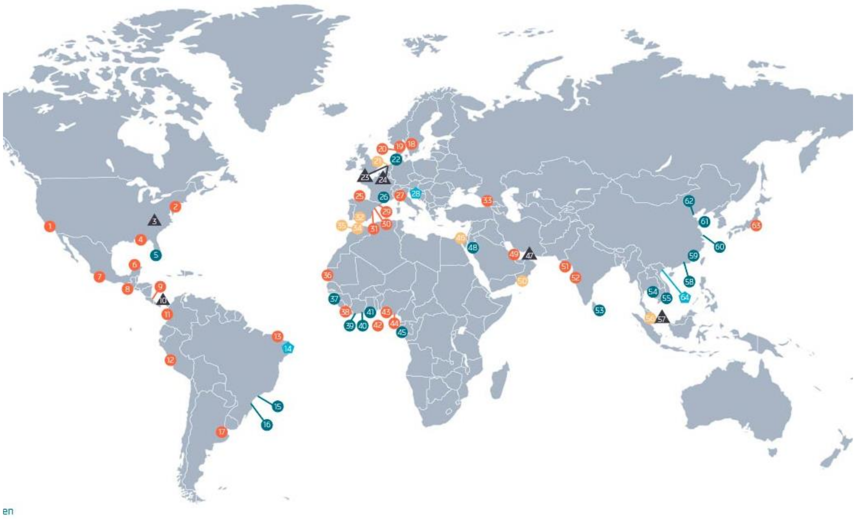


Figure 23 Global distribution of container terminals of APM Terminals

Source: APM Terminals

Other than the maritime industry, there are also many similar studies in the railway and airport sectors that can provide certain references, although there is still some difference in terms of price regulation, market structure, market power, primary users, operational characteristics, institutional structures, and revenue structure (Ye et al. 2012). In the railway sector, Preston (1996) suggested vertical integration in the railway system to achieve economies of scale. Werzel (2009) extends Preston`s research by arguing that vertical integration will undermine the industry’s efficiency at the same time. Markus Ksoll (2004) argues that a proper legal framework/regulation can eliminate the competition problem while preserving the advantages of vertical integration, such as higher productivity, quality, safety, and innovation of the rail system. Fumitoshi et al. (2005) compared three structures of the railway system: vertical separation, vertical integration, and the intermediate holding company model, finding the optimal railway structure depends on the intensity and type of traffic running on the network. Furthermore, Pedro Cantos et al. (2012) found the combination of vertical integration and horizontal integration is the best way to foster an increase in efficiency by comparing productivity efficiency levels in European rail systems. In air transport, Fu et al. (2011) reviewed how vertical cooperation can benefit the local economy and consumers but also help airlines gain monopoly power and harm competition. Barbot et al. (2009, 2013) and D`Alfonso et al. (2012) found that airport-airline collusion will positively affect integrated actor`s profits but also bring mixed effects on competition and welfare. Zhang et al. (2010), Sarawati et al. (2014), and Yang et al. (2015) all found a similar effect in profit-sharing schemes between airlines and airports. Forbes et al. (2010) compared the performance of an airline integrated with a regional partner and found that integrated airlines perform systematically better, especially on days with adverse weather and congestion.

However, very few papers addressed the effect of vertical integration between ports and shipping lines in the context of port competition and privatization (mixed duopoly). To the author`s best knowledge, Zhu et al. (2019) and Jiang et al. (2021) are the most related studies regarding the shipping line`s investment in the port's new capacity investment, but the study by Zhu et al. (2019) is based on a landlord port system, Jiang et al., (2021), on the other hand, included the two-port system, but omitted the setup of a mixed-duopoly. So, it is worth studying how vertical integration (investment in new port expansion by shipping line) can affect the optimal decisions of individual actors in the context of port competitions and port privatization. This paper extends the model applied by Zhu et al. (2019), shifting from the single landlord port model to the context of inter-port competition (mixed duopoly) with downstream competing shipping lines, and most importantly, we assume "n" is a small integer (representing the number of shipping lines severing at the port), rather than infinite in the assumption of Zhu et al. (2019), because, in reality, there are usually very few shipping lines calling at the port since the trend of mega ships and consolidation.

4.3 Model

4.3.1 Model setup

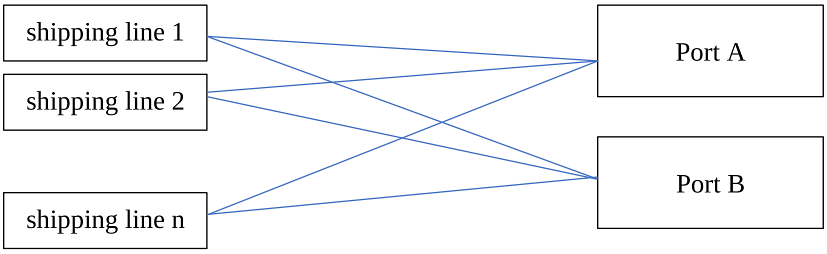


Figure 24 Setting of shipping lines and port A/B

Considering that *n* shipping lines provide the services of homogenous port A and port B symmetrically, the port authority of "landlord" port A will decide whether to allow the shipping line *i* invest in its new expansion capacity (Δk_a and Δk_{av}in non-integration and integration scenarios) with a share of s, and if so (0<s≤1), the shipping line i can get the corresponding share of total port operation revenue in return.

In the non-integration scenario ($s=0$), the symmetrical output of each shipping line at port A and port B is denoted as q_a and q_b, and the aggregated throughput for port A and port B are $Q_a = nq_a$ and, $Q_b = nq_b$

In the integrated scenario ($0<s\leq 1$), the output of shipping line *i* at port A and port B is defined: q_{ai} and q_{bi}, the rest of the shipping lines (n-1 shipping lines) at port A and B are defined: q_{aj} and q_{bj}. The aggregated throughput respectively is:
$Q_{av} = q_{ai} + (n-1)q_{ai}$, $Q_{bv} = q_{bi} + (n-1)q_{bi}$

So, the inverse demand function (non-integration and integration scenarios) is denoted as:

$$p_a = a - Q_a - bQ_b$$
$$p_b = a - Q_b - bQ_a$$

Where b is the service differentiation between port A and port B, $b \in (0,1)$

Assume that both ports are providing heterogeneous services with the same marginal operational cost: *c* for simplification.

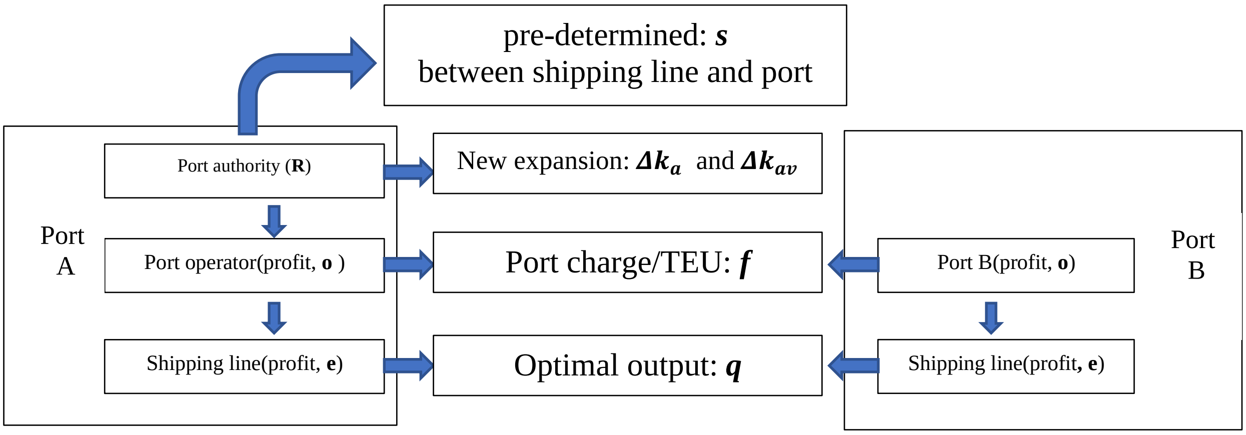


Figure 25 Principal of the model

Table 14 Parameters and their explanations

Name	Explanation
s	The share that the shipping line invests in the new expansion of Port A
m	Privatization level of Port A
a	a positive constant, and $a > c$
b	Service differentiation between Port A and Port B
c	Marginal operation cost of ports A and B (make both equivalent for simplification)
q_i	The cargo volume of shipping line *i*
n	Number of shipping lines serving port A and port B
Q_a, Q_b, Q_{av}, Q_{bv}	The aggregated cargo volume in port A and port B in both scenarios
p_a, p_b	The prices of services of port A and port B (reflection of generalized port charges)
Δk_a, Δk_{av}	Optimal capacity of new expansion of port A in both scenarios (to maximize its objective *R*)
k_a, k_{av}, k_b, k_o	The original capacity of port A(k_o) = capacity of Port B (k_b) Expanded capacity of port A ($k_a = k_0 + \Delta k_a$ and $k_{av} = k_0 + \Delta k_{av}$ respectively in both scenarios)
R_a, R_{av}	The objective of Port Authority A in both scenarios: Revenue of landlord Port A
o_a, o_{av}, o_b, o_{bv},	Objective of Port operators A and B in both scenarios, profit of port operator
f_a, f_{av} f_b, f_{bv},	Port charge (Terminal handling cost) by both port operators A and B in both scenarios(to maximize their profit *o*)
e_i	The profit of the shipping line *i*
q_a, q_{av} q_b, q_{bv},	Optimal cargo volume decided by the shipping line *i* in port A and port B in both scenarios (to maximize their profit *e*)
C_a, C_{av}	Consumer surplus in both scenarios
l	A positive constant (delay coefficient)
d	$d_i=lQ_i/k_i$, $i=a$ *or* b. Delay cost for Port A and B
r	Coefficient of the capital cost of new expansion

The two ports differ in their ownership structures, hence pursuing different objectives. Port A is the landlord port, consisting of the public port authority (PA) and private port operator (PO) with a mixed goal (R) of weighted consumer surplus and its profit, and port B is a private port aiming at maximizing its own profit.

So, in this paper, the chain of decision-making follows the sequence (adapted in lots of maritime game-theoretical papers) of port authority - port operator - shipping line. For the landlord port, its port authorities are to achieve a higher throughput, sustainable development, and higher social welfare; its private port operator is for its own profits, and shipping lines (outside the scope of the port) are for its own profits. In contrast, in a private port, the port authority and operator share a unified goal of maximizing profit. So, we assume that the PA of the landlord port will decide the optimal capacity of the new expansion: Δk_a and Δk_{av} Respectively, PO will decide exclusively the port charge per TEU respectively: f_a and f_b in the non-integration scenario, f_{av} and f_{bv} in the integration scenario, both with the same constant marginal container handling cost per TEU: c. The investment in the new expansion is considered to be covered by the port operator in the non-integration scenario and by the port operator/shipping line in the integration scenario. No concession fee is involved between the port authority and port operator in this paper because, mathematically, it will not affect the decision of the PA regarding optimal expansion and concession fee since the concession part gets offset or disappears in the social welfare formula. However, in reality, the expansion is usually a joint decision of PA and PO if PO decides to make a partial or full investment in the form of a joint venture or Build-operate-transfer model, Etc. In addition, the port charges, such as tariff, tug fee, pilot fee, ship due, etc., are based on the length/tonnage of the ship/dock, Etc. (related to the call-based charges collected by port authority/port operator/service provider), but like the terminal handling cost, stevedore cargo due are TEU-based (collected by the port operator), but to some extent, many per-call charges can be transferred into per-TEU charges without losing many details. There are also some papers arguing that in the air industry-shifting per-flight charge toward per-passenger charge is beneficial (Czerny et al., 2015, 2017). In this paper, following the decision procedure, we only consider per-TEU-based port charge by the port operator only (for profit-maximizing), the optimal new capacity of expansion by port authority only (for further development), so this separated arrangement is for simplicity and clarity of each actor.

Assume the capacity of port A before expansion: k_0, expansion capacity in the non-integration scenario: Δk_a (so, the capacity of port A in the non-integration scenario is $k_a = k_0 + \Delta k_a$), and expansion capacity in the integration scenario is Δk_{av} (so, the capacity of port A in the integration scenario is $k_{av} = k_0 + \Delta k_{av}$), the capacity of port b is k_b, and we assume $k_b = k_0$, which means two ports have the same initial capacity to ensure mathematical tractability and clear economic intuition.

Assume that the congestion of ports will result in the delay cost for shipping lines: d, which is proportional to the total throughput of that port, but the inverse proportion to the capacity of that port (Zheng et al., 2014), and we assume l is a constant parameter for both ports: $d_i = lQ_i / k_i$, $i=a$ *or* b.

In non-integration scenario (s=0):
Port A is a landlord port. The goal of its PO is defined as:

$$o_a = Q_a(f_a - c) - \Delta k_a r$$

Where r is the coefficient of capital cost, $\Delta k_a r$ is the capital cost of the new expansion.

The goal of its PA is defined as:

$$R_a = mC + o_a$$

Where C (consumer surplus, used as a proxy for public interest) is:
$C = 0.5({Q_a}^2 + {Q_b}^2 + 2Q_aQ_b)$, making it convex,
And m is a pre-determined parameter, representing the private level between (0,1), that when *m=1*, it presents a public port, and when *m=0*, as a private port.

Port B is a private port. The goal of the port is simply to maximize its profit as a whole:

$$o_b = Q_b(f_b - c)$$

The shipping lines are symmetrical in the non-integration scenario, so its profit is defined as:

$$e = q_a(p_a - f_a - d_a) + q_b(p_b - f_b - d_b)$$

Where q_a, q_b are the output of the shipping line to ports A and B, and $d_a = l\frac{Q_a}{k_a}$, $d_b = l\frac{Q_b}{k_b}$

In integration scenario (s∈(0,1]):
The goal of PO in port A is defined as:

$$o_{av} = \frac{\Delta k_{av} - s\Delta k_{av}}{k_{av}} Q_{av}(f_{av} - c) - (1 - s)\Delta k_{av} r$$

Where the first part is its proportion of its operation revenue, and the second part is the proportion of the capital cost of new joint expansion.

The goal of PA in port A is defined as:

$$R_{av} = mC_v + Q_{av}(f_{av} - c) - \Delta k_{av} r$$

Be noted that **the aggregated profit of port A is considered, rather than the non-integrated part of the profit** *(o_{av})*, due to the nature of joint venture.
Consumer surplus is defined as:

$$C_v = 0.5({Q_{av}}^2 + {Q_{bv}}^2 + 2Q_{av}Q_{bv})$$

The goal of the private port B is:

$$o_{bv} = Q_{bv}(f_{bv} - c)$$

For integrated shipping line *i*, it invests share "*s*" of the capital cost of the new expansion and receives the accordant operation profit of port A in return:

$$e_i = q_{ai}(p_{av} - f_{av} - d_{av}) + q_{bi}(p_{bv} - f_{bv} - d_{bv}) + \frac{s\Delta k_{av}}{k_{av}} Q_{av}(f_{av} - c) - s\,\Delta k_{av} r$$

On the other hand, the rival non-integrated shipping line *j* (total n-1 shipping lines) has the same profit function:

$$e_j = q_{aj}(p_{av} - f_{av} - d_{av}) + q_{bi}(p_{bv} - f_{bv} - d_{bv})$$

Based on the decision-making sequence above, the Port Authority, port operator, and shipping line will follow a 3-stage game:
Stage 1. PA of Port A decides the optimal new capacity Δk_a or Δk_{av} in two scenarios, so the new capacity of Port A: $k_a = k_0 + \Delta k_a$ and $k_{av} = k_0 + \Delta k_{av}$
Stage 2. PO of Port A and Port B will decide the optimal port charge: f_a and f_b or f_{av} and f_{bv} to maximize their own profits.
Stage 3. "*n*" shipping lines compete in output to maximize individual profit (*n* does not necessarily mean infinite).
Be noted that the share of "*s*" is predetermined by the agreement between shipping line *i* and port A, and the private level "*m*" is also predetermined based on the port`s own ownership structure.

4.3.2 The equilibrium of non-integration and integration scenarios

Based on the discussion above, the question emerges: whether the equilibrium in vertical integration will allow different parties to be better off compared to the equilibrium in the non-vertical integration scenario. Backward induction is applied, and the equilibrium of shipping lines, the port operator, and the port authority is solved in order.

In non-integration scenario (baseline, s=0)

In this scenario, symmetric shipping lines are competing for both routes to ports A and B by adjusting their outputs. First Order Condition (FOC) the profit function of each shipping line by its outputs (q_a and q_b): $\frac{\partial e}{\partial q_a} = \frac{\partial e}{\partial q_b} = 0$, we can get the optimal output of each route q_a and q_b

Substitute q_a and q_b into the profit function (e) of PO in ports A and B.

By maximizing the updated profit function of PO (e) of port A and port B, we can get the optimal port charge f_a and f_b.

$$\frac{\partial o_a}{\partial f_a} = \frac{\partial o_b}{\partial f_b} = 0$$

Be note that the sign of $f_a - f_b$ (see Appendix) is decided by the sign of $k_0 + \Delta k_a - k_b$. In other words, the bigger the overall capacity of port A surplus to Port B, the bigger the gap in port charges between port A and B. In the model setup, we assume $k_b = k_0$, so $f_a > f_b$

FOC the R_a (PA of port A) to obtain the optimal expansion Δk_a:

$$\frac{\partial R_a}{\partial \Delta k_a} = 0 \qquad (1)$$

We can get the function:

$$m\frac{\partial C}{\partial \Delta k_a} + \frac{\partial Q_a}{\partial \Delta k_a}(f_a - c) = r \qquad (2)$$

The first term in the *LHS* is the marginal contribution of the expansion to the consumer surplus **(C)**, and the second term in the bracket is the marginal contribution of the expansion to the operator`s profit at Port A. The whole equation is an equilibrium where the mixed and weighted marginal contribution of expansion to consumer surplus and profit should be equal to the unit capital cost "r". Be noted that there is no explicit symbolic solution for optimal Δk_a from this function.

We found that $\frac{\partial f_a}{\partial \Delta k_a} < 0, \frac{\partial f_b}{\partial \Delta k_a} < 0$, which means the higher expansion will lead to lower port charges at both ports. And $\frac{\partial (f_a - f_b)}{\partial\, \Delta k_a} > 0$, indicates the difference in port charge will enlarge with the increase of Δk_a

In integration with SL scenario (s∈(0,1])

Consider that shipping line i decides to share the capital cost of new expansion ($s\Delta k_{av} r$) of port A and receives the accordant proportion of revenue of the port operation ($\frac{s\Delta k_{av}}{k_{av}} Q_{av}(f_{av} - c)$, where $k_{av} = k_0 + \Delta k_{av}$) and compete with the rest of the symmetric *(n-1)* shipping lines "*j*".

FOC the profit function e_i and e_j simultaneously to obtain the optimal q_{ai}, q_{bi}, q_{aj}, q_{bj}.

$$\frac{\partial e_i}{\partial q_{ai}} = \frac{\partial e_i}{\partial q_{bi}} = \frac{\partial e_j}{\partial q_{aj}} = \frac{\partial e_j}{\partial q_{bj}} = 0$$

Substitute the q_{ai}, q_{bi}, q_{aj}, q_{bj} into the profit function of the port operators profit function (o_{av} and o_{bv}), and then FOC the updated profit function o_{av} and o_{bv} to get the optimal port charges f_{av} and f_{bv}:

$$\frac{\partial o_{av}}{\partial f_{av}} = \frac{\partial o_{bv}}{\partial f_{bv}} = 0$$

We found $f_{av}>f_{bv}$, $\frac{\partial f_{av}}{\partial s} > 0, \frac{\partial f_{bv}}{\partial s} = 0$, and when s=0, obviously $\Delta k_a = \Delta k_{av}$ and $f_a=f_{av}$ ($s=0$ indicating a non-integration scenario). Based on these arguments, when $s \in (0,1)$, **$f_{av}>f_a$ must hold**, showing that the integration will raise the port charge of the landlord port compared to the non-integration scenario. We also found $q_{ai}>q_{aj}$, indicating the integrated shipping line can outperform other rival shipping lines in landlord port A.

FOC R_{av} (PA of port A) to obtain the optimal expansion Δk_{av}:

$$\frac{\partial R_{av}}{\partial \Delta k_{av}} = 0 \qquad (3)$$

We get:

$$m\frac{\partial C_v}{\partial \Delta k_{av}} + \frac{\partial Q_{av}}{\partial \Delta k_{av}}(f_{av} - c) + Q_{av}\frac{\partial f_{av}}{\partial \Delta k_{av}} = r \qquad (4)$$

Similar to (2), the weighted marginal contribution of consumer surplus and profits should be equal to the unit capital cost "r" in the vertical integration. Be noted that there is no explicit symbolic solution for functions (2) and (4), but we can compare Δk_a and Δk_{av}.

To compare Δk_a and Δk_{av}, the results of functions (2) and (4) need to be checked carefully. "s" does not affect the *LHS* of function (2), which is equal to a constant "r". But, in function (4), $\frac{\partial C_v}{\partial s} = 0, \frac{\partial^2 C_v}{\partial s \partial \Delta k_{av}} = 0, \frac{\partial Q_{av}}{\partial s} = 0, \frac{\partial^2 Q_{av}}{\partial s \partial \Delta k_{av}} = 0$, and $\frac{\partial f_{av}}{\partial s} > 0, \frac{\partial^2 f_{av}}{\partial s \partial \Delta k_{av}} > 0$. When $s=0$, the LHS of function (2) should be equal to the LHS of function (4) and "r", implying- the same scenario: $\Delta k_a = \Delta k_{av}$. But when $0< s \leq 1$, the LHS of function (2) remains the same, but the LHS of function (4) is supposed to increase (only if $\Delta k_a = \Delta k_{av}$), because of $\frac{\partial C_v}{\partial s} = 0, \frac{\partial^2 C_v}{\partial s \partial \Delta k_{av}} = 0, \frac{\partial Q_{av}}{\partial s} = 0, \frac{\partial^2 Q_{av}}{\partial s \partial \Delta k_{av}} = 0$, and $\frac{\partial f_{av}}{\partial s} > 0, \frac{\partial^2 f_{av}}{\partial s \partial \Delta k_{av}} > 0$. So, to keep functions (2) and (4) hold, $\Delta k_{av} > \Delta k_a$ must hold because of $\frac{\partial Q_{av}}{\partial \Delta k_{av}} < 0$.

Given that $\Delta k_{av} > \Delta k_a$, so the vertical integration will push capacity expansion further in the integration scenario: $k_0 + \Delta k_a < k_0 + \Delta k_{av}$.

We also find that $Q_{av}>Q_a$, implying that vertical integration will increase the throughput of the integrated port A. However, the sign of $Q_{bv}-Q_b$ cannot be decided.

As for the effect of integration on the port charges of port operators, we found that. $\frac{\partial f_a}{\partial \Delta k_a} < 0$ and $\frac{\partial f_{av}}{\partial \Delta k_{av}} < 0$, but $f_{av} > f_a$ and $f_{bv} < f_b$. This means that expansion will drive the port charges down in both scenarios (because of the enlarged capacity), but the integration will grant port operator A the advantage to charge higher than the non-integration scenario (due to the market power gained from the integration). However, interestingly, port B has to impose a lower charge ($f_{bv} < f_b$) in the integration scenario than the non-integration one.

For the investment share "s" of the shipping line in the expansion capacity, we found that $\frac{\partial R_{av}}{\partial s} > 0$, indicating that a higher level of vertical integration will result in higher revenue for port A in the vertical integration scenario. In addition, $\frac{\partial (q_{ai}-q_a)}{\partial s} > 0$, $\frac{\partial (q_{ai}-q_{aj})}{\partial s} > 0$, indicating the higher integration level s between the port operator A and shipping line i will grant even more cargo throughput for shipping line i (q_{ai}) than the baseline of the non-integration scenario (q_a) and also its rival shipping lines (q_{aj}) in integration scenario.

For the profit of the port operator, expansion capacity will negatively affect the profitability of the port operator ($\frac{\partial f_a}{\partial \Delta k_a} < 0$ and $\frac{\partial f_{av}}{\partial \Delta k_{av}} < 0$), but higher optimal expansion capacity will increase social welfare, which may create conflicting interests between the public port authority and the private port operator.

4.4 Numeric example

The main objective of this paper is to investigate the impact of a carrier's vertical integration strategy in the context of two competing ports. However, due to the model's mathematical complexity, there is no explicit symbolic solution for the optimal expansion capacity (Δk_a and Δk_{av}). Therefore, the numerical experiment is presented to conduct the comparison. The parameters in our numerical analysis are set as follows: a=10, b=0.5, c=1, k0=1, l=0.2, n=100, r=0.01, and from the above analysis, the Δk_{av} is larger than Δk_a, so we assume Δk_a=0.1 and Δk_{av}=0.15 (the reason that Δk_{av} and Δk_a are given is that there is no explicit symbolic solution for both parameters). Be noted that in ***Figure 28***, the social welfare refers to the summation of the revenue of landlord port 1 and the profit of private port 2, with or without the aggregated profit of shipping lines (Note that shipping lines are usually international companies, and their profits are usually not included in the local social welfare).

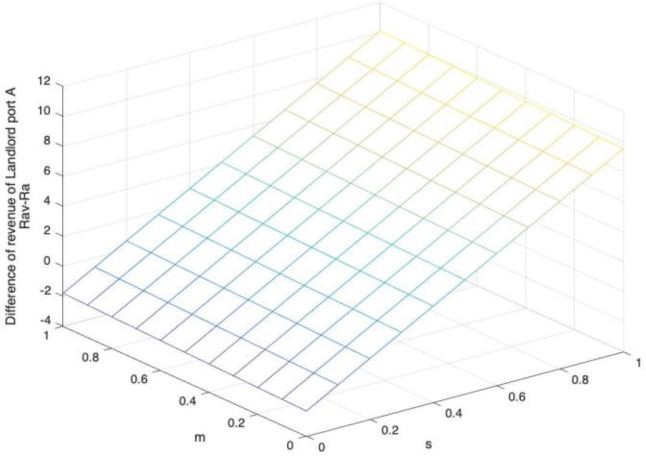


Figure 26 Difference of the revenue for Port A, before and after integration

Source: Authors` own elaboration

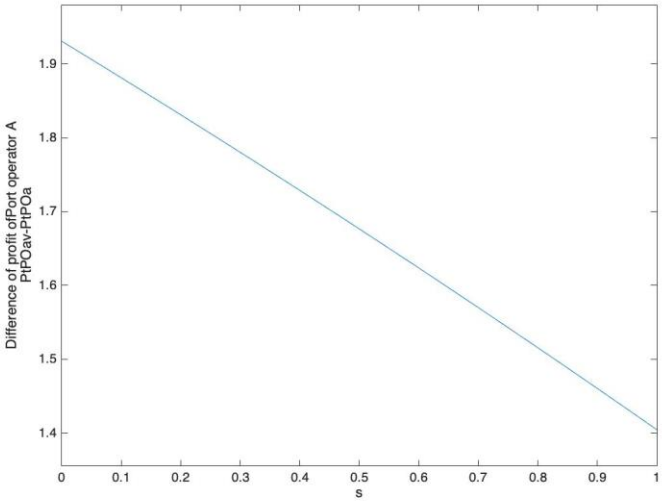


Figure 27 Difference of profit for Port operator A, before and after integration

Source: Authors` own elaboration

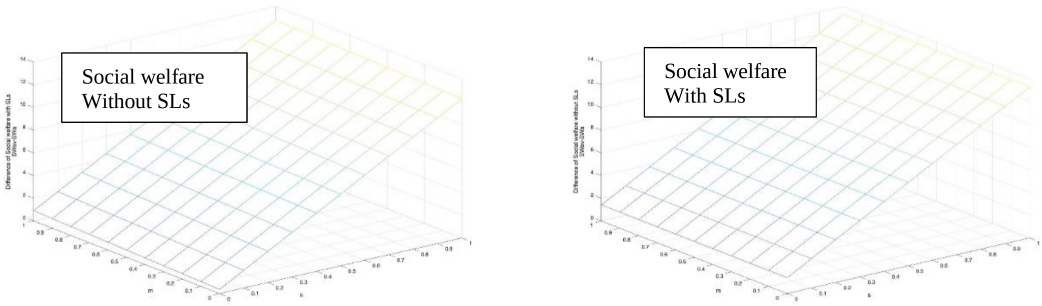


Figure 28 Difference of the social welfare with/without SLs, before and after integration

Source: Authors` own elaboration

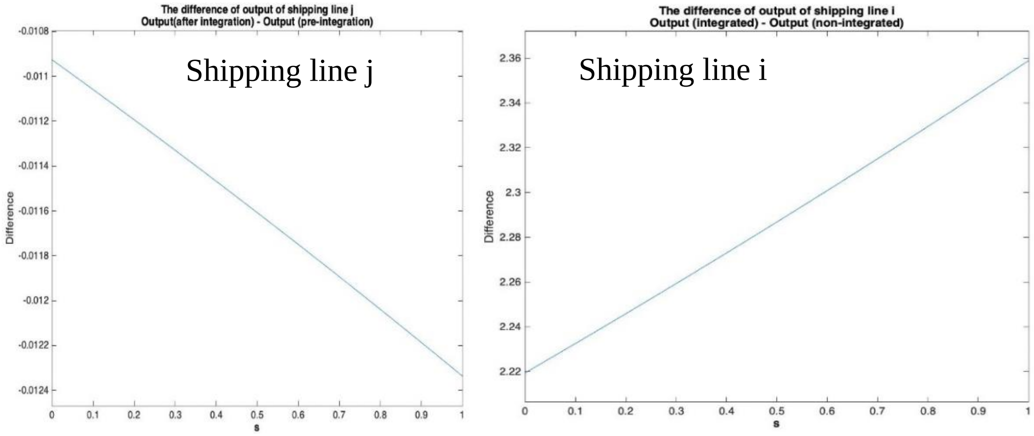


Figure 29 The difference of output for SL i and j, before and after integration

Source: Authors` own elaboration

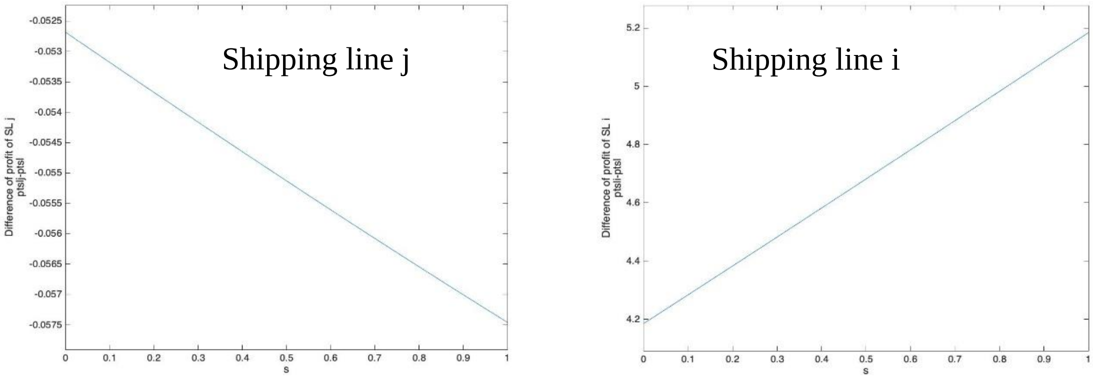


Figure 30 The difference of profit for SL i and j, before and after integration

Source: Authors` own elaboration

From the numeric example, we found that the terminal operator's vertical integration strategy (s) with carrier *i* may increase:

- the revenue of the landlord port A (see ***Figure 26***)
- the social welfare with/without SLs (see ***Figure 28***)
- the integrated carrier *i*`s own output and profit ($q_{ai}+q_{bi}-q_a-q_b>0$, *see **Figure 30**, **Figure 30***)

But it may damage the profitability of the port operator of Port A (see ***Figure 27***), and those non-integrated carriers j (see ***Figure 30**, **Figure 30***). In addition, the difference in profit for private port B after the integration is a positive constant, which indicates the profitability of port B is not affected by the integration (s). The reason behind is that: (1) private port B has to lower the optimal port charge ($f_{bv} < f_b$) after SL integration, on the other hand, (2) the sign of Q_{bv}-Q_b cannot be decided.

4.5 Conclusions

The shipping industry has undergone significant changes, with a growing trend of shipping lines becoming more involved in port management and terminal operations. Vertical integration in this context often involves port authorities leasing their assets and facilities to shipping lines through mutual agreements or concessions, enabling shipping lines to assume partial or full control of port management. This integration has become more prevalent in recent decades. Some deep-sea companies, like Maersk (APM Terminals) and COSCO (COSCO Shipping Ports), have developed their terminal operating holdings. These hybrid companies are adapting their strategies to embrace terminal operations, which allows them to generate a substantial portion of their profits (Notteboom et al., 2017).

The formation of shipping alliances and market consolidation, often facilitated by the deployment of larger vessels, has intensified competition among ports. This, in turn, has accelerated the trend of vertical integration between shipping lines and port management. Additionally, due to the long-term payback and significant capital costs associated with port investments, port authorities are increasingly seeking cooperation with shipping lines to share the financial burden. Furthermore, the ongoing process of port privatization adds complexity to the dynamics of vertical integration between ports and shipping lines.

Vertical integration is an important topic in economic literature. Although a lot of relevant studies have been carried out in different sectors of transportation, including maritime, air, and railway, a study about vertical integration in the context of duopoly competition is still needed. Specifically, it is interesting to investigate how vertical integration, such as new expansion, between a shipping line and a landlord port affects individual actors and related parameters in the context of port competitions.

The paper develops an economic model adapted from the study by Zhu et al. (2019), extending the context from a single landlord model to a mixed duopoly model. This model contains port authority, competing port operators, and shipping lines in a multi-stage game. Port A is the landlord port, consisting of a public port authority and a private port operator with a mixed goal of consumer surplus and profit, and port B is a private port aiming at maximizing its own profit. So, in this paper, the chain of decision-making follows the sequence (adapted in lots of maritime game-theoretical papers) as the port authority - port operator - and shipping line. For a landlord port, its port authority is to achieve higher throughput, sustainable development, and higher social welfare; its private port operator is for its own profits; and shipping lines (outside the scope of the port) are for its own profits. In contrast, in a private port, its port authority and operator share a unified goal of maximizing profit. The investment in the new expansion is covered by the port operator in the non-integration scenario and by the port operator and shipping line in the integration scenario.

The study results indicate that vertical integration could be a source of synergy for maritime transportation and help the port and shipping line gain competitiveness. The model result suggests a higher integration level can result in a higher port capacity and throughput, higher port charge for the landlord port A, and higher output (cargo volume) of the integrated shipping line i, which is consistent with the results from Zhu et al. (2019). On the other hand, the private port operator B may suffer a loss because of the lower optimal port charge in the integration scenario with the uncertainty on its throughput changes due to integration. The numeric example, serving as a supplement for the theoretical results, shows that the integration can raise the output and profit of the participating shipping line, outperforming not only itself in the baseline scenario, but also the rival shipping lines in the vertical integration scenario in landlord port A. In other words, the participation of shipping lines in vertical integration with terminals can gain certain market power at the cost of other non-integrated rival shipping lines. In addition, the integration, in the numeric example part, shows the positive effects on the revenue of landlord port and the social welfare, which is different from the result by Jiang et al., (2021), and this is probably because of different analytical model and setups. However, the incentive for port operator A to finance the expansion may not be that clear because the increased capacity may negatively affect its own profitability.

The trend of cooperation and integration between giant shipping lines and ports can be backed by our results. This study shows that the new capacity joint investment can potentially help the port (terminal operator) and shipping lines work together to gain certain competitiveness. For instance, After COSCO acquired 67% of the share in 2016, the Port of Piraeus achieved an increase of container throughput by 28.3% from 2017-2021, reaching 5.3 million TEUs, and ranks as the fifth biggest port in Europe and the third biggest in the Mediterranean Sea. Among the port of calls, COSCO calls at the port more frequently, which is consistent with what Notteboom et al. (2017) found about the relationship between the SL`s share in the port and the port of call of the SLs and Shipping Alliance. It is clear, to some extent, that the integration by new capacity investment would help the SL to generate more cargo volume and help the port achieve a higher “throughput” goal, desired by most of the port authority and government, due to the shortage in investment and the desired spillover effects on the local economy.

But it is also worth noting that integration is not a cure for all. Our study shows that the involvement of the shipping line in the expansion investment will damage (landlord) port operator`s own profitability/motivation to invest, mostly because of the extra capacity added into the market. Furthermore, for the government and port authority, in practice, sole reliance on the shipping line is a double-blade sword that, on the one hand, indeed solves the problem of shortage of investment (e.g., to fulfill the guarantee of a certain level of capacity in concession) and help the port achieve a throughput goal, on the other hand, its flexibility will be frequently challenged by, such as the loose-sand cargo from the re-routing issues due to the dynamics of shipping alliance, or incompetency of integrated SL on its concession agreement, or even the concerns of overcapacity which is already happening in some parts of the world. Besides, the market power gained from the integration by the integrated SL and the landlord port should also be addressed by the government since it will damage the "fair" positions in competition among the SLs and ports and, in return, accelerate the situation of sole reliance on a single shipping line, making the competitiveness of the port fragile.

In general, the decision of optimal expansion capacity by port authority creates certain conflicts between private and public interests. Therefore, the port authority and government should carefully review the status of all parties involved in the expansion plans and regulations. For instance, the Chilean government restricts a maximum 40% share of the port in the concession agreement, and in contrast, Greece and Spain put little restrictions on their port regarding the private/foreign shares. The examples show that, from the government perspective, integration between SL and port should be thoroughly investigated, taking account of not just the shipping and port-related issues into consideration.

To simplify the mathematical calculation, there are some simplifications and limitations of the proposed modeling exercise: (1) the linear demand function (the limitation is addressed in the last part of Chapter 3.4), (2) the linear delay cost function (It does not reflect the effects of shipping line`s economies of scale on delay cost), (3) assumption of shipping line directly investing in the new capacity (in practice, this investment is usually made by the subsidiary/sister company of the shipping line), (4) allocation of the profit from the expansion based on the share of investment (In practice, the share is mainly decided by the bargaining process among the terminal operator, port authority/government, and shipping lines), (5) the assumption of same capacity of the two initial ports (6) constant marginal cost of two ports (In practice, different ports may adopt different cost structure to provide differentiated service, see Cullinane et al., 2005)

For future studies, it may be interesting to extend the vertical integration to the inland transport chains (see De Borger et al., 2008; Zondag et al., 2010). In addition, it is of particular interest to examine the implications of ownership differences among shipping lines (e.g., COSCO shipping line, as a semi-public SL, with the rest of profit-driven SLs, but be noted that the semi-public SL has to share the same social objective with the port; otherwise it will be considered as a regular profit-driven SL), within the framework of a port mixed duopoly. Such an investigation may encompass the assessment of various scenarios predicated on three distinct criteria, namely, integration-only, mixed-ownership (of shipping lines)-only, and integration-mixed ownership (of shipping lines) in tandem, to reveal the combined effects of the ownership and integration on shipping lines and ports.

Appendix

Be noted:
dka represents Δk_a,
dkav represents Δk_{av}
k0 represents k_0

- **The optimal quantity q_a and q_b in non-integration scenario**

Intermediate result

qa=((dka + k0)*(a*k0 + a*l - fa*k0 - fa*l - a*b*k0 + b*fb*k0))/(2*n*(- b^2*k0^2 - dka*b^2*k0 + k0^2 + 2*k0*l + dka*k0 + l^2 + dka*l))

qb=(k0*(a*dka - dka*fb + a*k0 + a*l - fb*k0 - fb*l - a*b*dka + b*dka*fa - a*b*k0 + b*fa*k0))/(2*n*(- b^2*k0^2 - dka*b^2*k0 + k0^2 + 2*k0*l + dka*k0 + l^2 + dka*l))

fa=(2*a*k0^2 + 2*a*l^2 + 2*c*k0^2 + 2*c*l^2 - a*b^2*k0^2 + 2*a*dka*k0 + 2*a*dka*l + 2*c*dka*k0 + 2*c*dka*l + 4*a*k0*l + 4*c*k0*l - a*b*k0^2 + b*c*k0^2 - a*b^2*dka*k0 - a*b*dka*k0 + b*c*dka*k0 - a*b*k0*l + b*c*k0*l)/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)

fb=(2*a*k0^2 + 2*a*l^2 + 2*c*k0^2 + 2*c*l^2 - a*b^2*k0^2 + 2*a*dka*k0 + 2*a*dka*l + 2*c*dka*k0 + 2*c*dka*l + 4*a*k0*l + 4*c*k0*l - a*b*k0^2 + b*c*k0^2 - a*b^2*dka*k0 - a*b*dka*k0 - a*b*dka*l + b*c*dka*k0 + b*c*dka*l - a*b*k0*l + b*c*k0*l)/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)

Final result

q_a=((dka + k0)*(k0 + l)*(a - c)*(- b^2*k0^2 - dka*b^2*k0 - b*k0^2 - b*k0*l - dka*b*k0 + 2*k0^2 + 4*k0*l + 2*dka*k0 + 2*l^2 + 2*dka*l))/(2*n*(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)*(- b^2*k0^2 - dka*b^2*k0 + k0^2 + 2*k0*l + dka*k0 + l^2 + dka*l))

q_b=-(k0*(a - c)*(dka + k0 + l)*(b^2*k0^2 + dka*b^2*k0 + b*k0^2 + b*k0*l + dka*b*k0 + dka*b*l - 2*k0^2 - 4*k0*l - 2*dka*k0 - 2*l^2 - 2*dka*l))/(2*n*(b^4*dka^2*k0^2 + 2*b^4*dka*k0^3 + b^4*k0^4 - 5*b^2*dka^2*k0^2 - 5*b^2*dka^2*k0*l - 10*b^2*dka*k0^3 - 15*b^2*dka*k0^2*l - 5*b^2*dka*k0*l^2 - 5*b^2*k0^4 - 10*b^2*k0^3*l - 5*b^2*k0^2*l^2 + 4*dka^2*k0^2 + 8*dka^2*k0*l + 4*dka^2*l^2 + 8*dka*k0^3 + 24*dka*k0^2*l + 24*dka*k0*l^2 + 8*dka*l^3 + 4*k0^4 + 16*k0^3*l + 24*k0^2*l^2 + 16*k0*l^3 + 4*l^4))

f_a=(2*a*k0^2 + 2*a*l^2 + 2*c*k0^2 + 2*c*l^2 - a*b^2*k0^2 + 2*a*dka*k0 + 2*a*dka*l + 2*c*dka*k0 + 2*c*dka*l + 4*a*k0*l + 4*c*k0*l - a*b*k0^2 + b*c*k0^2 - a*b^2*dka*k0 - a*b*dka*k0 + b*c*dka*k0 - a*b*k0*l + b*c*k0*l)/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)

f_b=(2*a*k0^2 + 2*a*l^2 + 2*c*k0^2 + 2*c*l^2 - a*b^2*k0^2 + 2*a*dka*k0 + 2*a*dka*l + 2*c*dka*k0 + 2*c*dka*l + 4*a*k0*l + 4*c*k0*l - a*b*k0^2 + b*c*k0^2 - a*b^2*dka*k0 - a*b*dka*k0 - a*b*dka*l + b*c*dka*k0 + b*c*dka*l - a*b*k0*l + b*c*k0*l)/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)

- **The optimal q_{ai}, q_{bi}, q_{aj}, q_{bj} f_{av}, f_{bv} in integration scenario**

Intermediate result

qai=(a*k0^2 - fav*k0^2 + a*dkav*k0 + a*dkav*l - dkav*fav*k0 - dkav*fav*l + a*k0*l - fav*k0*l - a*b*k0^2 + b*fbv*k0^2 - 2*c*dkav*k0*s - 2*c*dkav*l*s + 2*dkav*fav*k0*s + 2*dkav*fav*l*s - a*b*dkav*k0 + b*dkav*fbv*k0)/(3*(- b^2*k0^2 - dkav*b^2*k0 + k0^2 + 2*k0*l + dkav*k0 + l^2 + dkav*l))

qbi=(k0*(a*dkav - dkav*fbv + a*k0 + a*l - fbv*k0 - fbv*l - a*b*dkav + b*dkav*fav - a*b*k0 + b*fav*k0 + 2*b*c*dkav*s - 2*b*dkav*fav*s))/(3*(- b^2*k0^2 - dkav*b^2*k0 + k0^2 + 2*k0*l + dkav*k0 + l^2 + dkav*l))

qaj=(a*k0^2 - fav*k0^2 + a*dkav*k0 + a*dkav*l - dkav*fav*k0 - dkav*fav*l + a*k0*l - fav*k0*l - a*b*k0^2 + b*fbv*k0^2 + c*dkav*k0*s + c*dkav*l*s - dkav*fav*k0*s - dkav*fav*l*s - a*b*dkav*k0 + b*dkav*fbv*k0)/(3*(n - 1)*(- b^2*k0^2 - dkav*b^2*k0 + k0^2 + 2*k0*l + dkav*k0 + l^2 + dkav*l))

qbj=(k0*(a*dkav - dkav*fbv + a*k0 + a*l - fbv*k0 - fbv*l - a*b*dkav + b*dkav*fav - a*b*k0 + b*fav*k0 - b*c*dkav*s + b*dkav*fav*s))/(3*(n - 1)*(- b^2*k0^2 - dkav*b^2*k0 + k0^2 + 2*k0*l + dkav*k0 + l^2 + dkav*l))

Final result

q_{ai}=(2*(dkav + k0)*(k0 + l)*(a - c)*(dkav + k0 + dkav*s)*(- b^2*k0^2 - dkav*b^2*k0 - b*k0^2 - b*k0*l - dkav*b*k0 + 2*k0^2 + 4*k0*l + 2*dkav*k0 + 2*l^2 + 2*dkav*l))/(3*(2*dkav + 2*k0 - dkav*s)*(b^4*dkav^2*k0^2 + 2*b^4*dkav*k0^3 + b^4*k0^4 - 5*b^2*dkav^2*k0^2 - 5*b^2*dkav^2*k0*l - 10*b^2*dkav*k0^3 - 15*b^2*dkav*k0^2*l - 5*b^2*dkav*k0*l^2 - 5*b^2*k0^4 - 10*b^2*k0^3*l - 5*b^2*k0^2*l^2 + 4*dkav^2*k0^2 + 8*dkav^2*k0*l + 4*dkav^2*l^2 + 8*dkav*k0^3 + 24*dkav*k0^2*l + 24*dkav*k0*l^2 + 8*dkav*l^3 + 4*k0^4 + 16*k0^3*l + 24*k0^2*l^2 + 16*k0*l^3 + 4*l^4))

q_{bi}=-(k0*(a - c)*(2*b*k0^4 - 12*dkav*k0^3 - 4*dkav^3*k0 - 4*dkav*l^3 - 4*dkav^3*l - 4*k0*l^3 - 12*k0^3*l - 4*k0^4 + 2*b^2*k0^4 - 12*dkav^2*k0^2 - 8*dkav^2*l^2 - 12*k0^2*l^2 + 2*dkav*k0^3*s + 2*dkav^3*k0*s + 2*dkav*l^3*s + 2*dkav^3*l*s + 6*b*dkav^2*k0^2 + 6*b^2*dkav*k0^3 + 2*b^2*dkav^3*k0 + 2*b*dkav^2*l^2 + 2*b*k0^2*l^2 + 2*b^2*k0^3*l + 4*dkav^2*k0^2*s + 4*dkav^2*l^2*s + 6*b^2*dkav^2*k0^2 + 6*b*dkav*k0^3 + 2*b*dkav^3*k0 + 2*b*dkav^3*l + 4*b*k0^3*l - 20*dkav*k0*l^2 - 28*dkav*k0^2*l - 20*dkav^2*k0*l - 8*b^2*dkav^2*k0^2*s - 6*b^3*dkav^2*k0^2*s + 4*b*dkav*k0*l^2 + 10*b*dkav*k0^2*l + 8*b*dkav^2*k0*l + 5*b*dkav*k0^3*s + 5*b*dkav^3*k0*s + 5*b*dkav^3*l*s + 6*dkav*k0*l^2*s + 6*dkav*k0^2*l*s + 8*dkav^2*k0*l*s + 4*b^2*dkav*k0^2*l + 2*b^2*dkav^2*k0*l + 10*b*dkav^2*k0^2*s - 4*b^2*dkav*k0^3*s - 4*b^2*dkav^3*k0*s - 3*b^3*dkav*k0^3*s - 3*b^3*dkav^3*k0*s + 5*b*dkav^2*l^2*s - 4*b^2*dkav*k0^2*l*s - 4*b^2*dkav^2*k0*l*s + 5*b*dkav*k0*l^2*s + 10*b*dkav*k0^2*l*s + 15*b*dkav^2*k0*l*s))/(3*(2*dkav + 2*k0 - dkav*s)*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)*(- b^2*k0^2 - dkav*b^2*k0 + k0^2 + 2*k0*l + dkav*k0 + l^2 + dkav*l))

q_{aj}=(2*(dkav + k0)*(k0 + l)*(a - c)*(dkav + k0 - 2*dkav*s)*(- b^2*k0^2 - dkav*b^2*k0 - b*k0^2 - b*k0*l - dkav*b*k0 + 2*k0^2 + 4*k0*l + 2*dkav*k0 + 2*l^2 + 2*dkav*l))/(3*(n - 1)*(2*dkav +

2*k0 - dkav*s)*(b^4*dkav^2*k0^2 + 2*b^4*dkav*k0^3 + b^4*k0^4 - 5*b^2*dkav^2*k0^2 - 5*b^2*dkav^2*k0*l - 10*b^2*dkav*k0^3 - 15*b^2*dkav*k0^2*l - 5*b^2*dkav*k0*l^2 - 5*b^2*k0^4 - 10*b^2*k0^3*l - 5*b^2*k0^2*l^2 + 4*dkav^2*k0^2 + 8*dkav^2*k0*l + 4*dkav^2*l^2 + 8*dkav*k0^3 + 24*dkav*k0^2*l + 24*dkav*k0*l^2 + 8*dkav*l^3 + 4*k0^4 + 16*k0^3*l + 24*k0^2*l^2 + 16*k0*l^3 + 4*l^4))

q_{bj}=-(k0*(a - c)*(2*b*k0^4 - 12*dkav*k0^3 - 4*dkav^3*k0 - 4*dkav*l^3 - 4*dkav^3*l - 4*k0*l^3 - 12*k0^3*l - 4*k0^4 + 2*b^2*k0^4 - 12*dkav^2*k0^2 - 8*dkav^2*l^2 - 12*k0^2*l^2 + 2*dkav*k0^3*s + 2*dkav^3*k0*s + 2*dkav*l^3*s + 2*dkav^3*l*s + 6*b*dkav^2*k0^2 + 6*b^2*dkav*k0^3 + 2*b^2*dkav^3*k0 + 2*b*dkav^2*l^2 + 2*b*k0^2*l^2 + 2*b^2*k0^3*l + 4*dkav^2*k0^2*s + 4*dkav^2*l^2*s + 6*b^2*dkav^2*k0^2 + 6*b*dkav*k0^3 + 2*b*dkav^3*k0 + 2*b*dkav^3*l + 4*b*k0^3*l - 20*dkav*k0*l^2 - 28*dkav*k0^2*l - 20*dkav^2*k0*l + 4*b^2*dkav^2*k0^2*s + 6*b^3*dkav^2*k0^2*s + 4*b*dkav*k0*l^2 + 10*b*dkav*k0^2*l + 8*b*dkav^2*k0*l - 7*b*dkav*k0^3*s - 7*b*dkav^3*k0*s - 7*b*dkav^3*l*s + 6*dkav*k0*l^2*s + 6*dkav*k0^2*l*s + 8*dkav^2*k0*l*s + 4*b^2*dkav*k0^2*l + 2*b^2*dkav^2*k0*l - 14*b*dkav^2*k0^2*s + 2*b^2*dkav*k0^3*s + 2*b^2*dkav^3*k0*s + 3*b^3*dkav*k0^3*s + 3*b^3*dkav^3*k0*s - 7*b*dkav^2*l^2*s + 2*b^2*dkav*k0^2*l*s + 2*b^2*dkav^2*k0*l*s - 7*b*dkav*k0*l^2*s - 14*b*dkav*k0^2*l*s - 21*b*dkav^2*k0*l*s))/(3*(n - 1)*(2*dkav + 2*k0 - dkav*s)*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)*(- b^2*k0^2 - dkav*b^2*k0 + k0^2 + 2*k0*l + dkav*k0 + l^2 + dkav*l))

f_{av}=(4*a*k0^3 + 4*c*k0^3 - 2*a*b^2*k0^3 - 2*a*b*k0^3 + 2*b*c*k0^3 + 8*a*dkav*k0^2 + 4*a*dkav^2*k0 + 4*a*dkav*l^2 + 4*a*dkav^2*l + 8*c*dkav*k0^2 + 4*c*dkav^2*k0 + 4*c*dkav*l^2 + 4*c*dkav^2*l + 4*a*k0*l^2 + 8*a*k0^2*l + 4*c*k0*l^2 + 8*c*k0^2*l - 4*a*b*dkav*k0^2 - 2*a*b*dkav^2*k0 + 4*b*c*dkav*k0^2 + 2*b*c*dkav^2*k0 - 2*a*b*k0^2*l + 2*b*c*k0^2*l - 4*c*dkav*k0^2*s - 4*c*dkav^2*k0*s - 4*c*dkav*l^2*s - 4*c*dkav^2*l*s - 4*a*b^2*dkav*k0^2 - 2*a*b^2*dkav^2*k0 + 12*a*dkav*k0*l + 12*c*dkav*k0*l + b^2*c*dkav*k0^2*s + b^2*c*dkav^2*k0*s - 2*a*b*dkav*k0*l + 2*b*c*dkav*k0*l - 8*c*dkav*k0*l*s)/((2*dkav + 2*k0 - dkav*s)*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l))

f_{bv}=(2*a*k0^2 + 2*a*l^2 + 2*c*k0^2 + 2*c*l^2 - a*b^2*k0^2 + 2*a*dkav*k0 + 2*a*dkav*l + 2*c*dkav*k0 + 2*c*dkav*l + 4*a*k0*l + 4*c*k0*l - a*b*k0^2 + b*c*k0^2 - a*b^2*dkav*k0 - a*b*dkav*k0 - a*b*dkav*l + b*c*dkav*k0 + b*c*dkav*l - a*b*k0*l + b*c*k0*l)/(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)

- **Detailed calculation process**

f_a-f_b=(b*dka*l*(a - c))/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l) >0

$\frac{\partial f_a}{\partial \Delta k_a}$ =-(b^2*k0*l*(a - c)*(2*k0 + 2*l + b*k0))/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)^2 >0

$\frac{\partial f_b}{\partial \Delta k_a}$ =-(2*b*l*(k0 + l)*(a - c)*(2*k0 + 2*l + b*k0))/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)^2 >0

$\frac{\partial (f_a - f_b)}{\partial\ \Delta k_a}$ =(b*l*(a - c)*(- b^2*k0^2 + 4*k0^2 + 8*k0*l + 4*l^2))/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)^2 >0

f_{av}-f_{bv}=(dkav*(a - c)*(2*k0^2*s + 2*l^2*s - b^2*k0^2*s + 2*b*dkav*l + 2*b*k0*l + 2*dkav*k0*s + 2*dkav*l*s + 4*k0*l*s - b*k0^2*s - b*dkav*k0*s - b*dkav*l*s - b*k0*l*s - b^2*dkav*k0*s))/((2*dkav + 2*k0 - dkav*s)*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)) >0

$\frac{\partial f_{av}}{\partial s}$=(2*dkav*(dkav + k0)*(a - c)*(- b^2*k0^2 - dkav*b^2*k0 - b*k0^2 - b*k0*l - dkav*b*k0 + 2*k0^2 + 4*k0*l + 2*dkav*k0 + 2*l^2 + 2*dkav*l))/((2*dkav + 2*k0 - dkav*s)^2*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)) >0

$\frac{\partial f_{bv}}{\partial s}$=0

q_{ai}-q_{aj}=(2*(dkav + k0)*(k0 + l)*(a - c)*(dkav*n - 2*k0 - 2*dkav + dkav*s + k0*n + dkav*n*s)*(- b^2*k0^2 - dkav*b^2*k0 - b*k0^2 - b*k0*l - dkav*b*k0 + 2*k0^2 + 4*k0*l + 2*dkav*k0 + 2*l^2 + 2*dkav*l))/(3*(n - 1)*(2*dkav + 2*k0 - dkav*s)*(b^4*dkav^2*k0^2 + 2*b^4*dkav*k0^3 + b^4*k0^4 - 5*b^2*dkav^2*k0^2 - 5*b^2*dkav^2*k0*l - 10*b^2*dkav*k0^3 - 15*b^2*dkav*k0^2*l - 5*b^2*dkav*k0*l^2 - 5*b^2*k0^4 - 10*b^2*k0^3*l - 5*b^2*k0^2*l^2 + 4*dkav^2*k0^2 + 8*dkav^2*k0*l + 4*dkav^2*l^2 + 8*dkav*k0^3 + 24*dkav*k0^2*l + 24*dkav*k0*l^2 + 8*dkav*l^3 + 4*k0^4 + 16*k0^3*l + 24*k0^2*l^2 + 16*k0*l^3 + 4*l^4)) >0

$\frac{\partial^2 f_{av}}{\partial s \partial \Delta k_{av}}$= =(2*k0*(a - c)*(48*dkav*k0^4 - 8*b*k0^5 + 16*dkav*l^4 + 16*k0*l^4 + 64*k0^4*l + 16*k0^5 - 12*b^2*k0^5 + 2*b^3*k0^5 + 2*b^4*k0^5 + 48*dkav^2*k0^3 + 16*dkav^3*k0^2 + 32*dkav^2*l^3 + 16*dkav^3*l^2 + 64*k0^2*l^3 + 96*k0^3*l^2 + 8*dkav*k0^4*s + 8*dkav*l^4*s - 24*b*dkav^2*k0^3 - 8*b*dkav^3*k0^2 - 36*b^2*dkav*k0^4 + 6*b^3*dkav*k0^4 + 6*b^4*dkav*k0^4 - 8*b*k0^2*l^3 - 24*b*k0^3*l^2 - 24*b^2*k0^4*l + 2*b^3*k0^4*l + 192*dkav*k0^2*l^2 + 112*dkav^2*k0*l^2 + 128*dkav^2*k0^2*l + 16*dkav^2*k0^3*s + 8*dkav^3*k0^2*s + 16*dkav^2*l^3*s + 8*dkav^3*l^2*s - 36*b^2*dkav^2*k0^3 - 12*b^2*dkav^3*k0^2 + 6*b^3*dkav^2*k0^3 + 2*b^3*dkav^3*k0^2 + 6*b^4*dkav^2*k0^3 + 2*b^4*dkav^3*k0^2 - 4*b^2*dkav^3*l^2 - 12*b^2*k0^3*l^2 - 24*b*dkav*k0^4 - 24*b*k0^4*l + 96*dkav*k0*l^3 + 160*dkav*k0^3*l + 32*dkav^3*k0*l - 28*b^2*dkav*k0^2*l^2 - 20*b^2*dkav^2*k0*l^2 - 56*b^2*dkav^2*k0^2*l - 2*b^3*dkav^2*k0^2*l - 12*b^2*dkav^2*k0^3*s - 6*b^2*dkav^3*k0^2*s + 2*b^3*dkav^2*k0^3*s + b^3*dkav^3*k0^2*s + 2*b^4*dkav^2*k0^3*s + b^4*dkav^3*k0^2*s + 2*b^2*dkav^3*l^2*s - 8*b*dkav*k0*l^3 - 56*b*dkav*k0^3*l - 8*b*dkav^3*k0*l - 4*b*dkav*k0^4*s + 32*dkav*k0*l^3*s + 32*dkav*k0^3*l*s + 16*dkav^3*k0*l*s - 40*b*dkav*k0^2*l^2 - 16*b*dkav^2*k0*l^2 - 40*b*dkav^2*k0^2*l - 64*b^2*dkav*k0^3*l - 16*b^2*dkav^3*k0*l + 2*b^3*dkav*k0^3*l - 2*b^3*dkav^3*k0*l - 8*b*dkav^2*k0^3*s - 4*b*dkav^3*k0^2*s - 6*b^2*dkav*k0^4*s + b^3*dkav*k0^4*s + b^4*dkav*k0^4*s + 48*dkav*k0^2*l^2*s + 48*dkav^2*k0*l^2*s + 48*dkav^2*k0^2*l*s - 12*b*dkav*k0^2*l^2*s - 8*b*dkav^2*k0*l^2*s - 16*b*dkav^2*k0^2*l*s - 12*b^2*dkav*k0^3*l*s -

4*b^2*dkav^3*k0*l*s + b^3*dkav*k0^3*l*s + b^3*dkav^3*k0*l*s - 6*b^2*dkav*k0^2*l^2*s - 4*b^2*dkav^2*k0*l^2*s - 16*b^2*dkav^2*k0^2*l*s + 2*b^3*dkav^2*k0^2*l*s - 4*b*dkav*k0*l^3*s - 12*b*dkav*k0^3*l*s - 4*b*dkav^3*k0*l*s))/((2*dkav + 2*k0 - dkav*s)^3*(4*dkav*k0 + 4*dkav*l + 8*k0*l + 4*k0^2 + 4*l^2 - b^2*k0^2 - b^2*dkav*k0)^2) >0

$\frac{\partial f_a}{\partial \Delta k_a}$= -(b^2*k0*l*(a - c)*(2*k0 + 2*l + b*k0))/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)^2 <0

$\frac{\partial f_{av}}{\partial \Delta k_{av}}$=-(2*k0*(a - c)*(4*b^2*k0^3*l - 8*l^4*s - 16*dkav*k0^3*s - 16*dkav*l^3*s - 32*k0*l^3*s - 32*k0^3*l*s - 8*k0^4*s + 2*b^3*k0^3*l + 6*b^2*k0^4*s - b^3*k0^4*s - b^4*k0^4*s - 8*dkav^2*k0^2*s - 8*dkav^2*l^2*s - 48*k0^2*l^2*s + 4*b^2*dkav^2*l^2 + 4*b^2*k0^2*l^2 + 4*b*k0^4*s + 6*b^2*dkav^2*k0^2*s - b^3*dkav^2*k0^2*s - b^4*dkav^2*k0^2*s - 2*b^2*dkav^2*l^2*s + 6*b^2*k0^2*l^2*s + 8*b*dkav*k0^3*s + 4*b*k0*l^3*s + 12*b*k0^3*l*s - 48*dkav*k0*l^2*s - 48*dkav*k0^2*l*s - 16*dkav^2*k0*l*s + 8*b^2*dkav*k0*l^2 + 8*b^2*dkav*k0^2*l + 4*b^2*dkav^2*k0*l + 4*b^3*dkav*k0^2*l + 2*b^3*dkav^2*k0*l + 4*b*dkav^2*k0^2*s + 12*b^2*dkav*k0^3*s - 2*b^3*dkav*k0^3*s - 2*b^4*dkav*k0^3*s + 12*b*k0^2*l^2*s + 12*b^2*k0^3*l*s - b^3*k0^3*l*s + 4*b^2*dkav*k0*l^2*s + 16*b^2*dkav*k0^2*l*s + 4*b^2*dkav^2*k0*l*s - 2*b^3*dkav*k0^2*l*s - b^3*dkav^2*k0*l*s + 8*b*dkav*k0*l^2*s + 16*b*dkav*k0^2*l*s + 4*b*dkav^2*k0*l*s))/((2*dkav + 2*k0 - dkav*s)^2*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)^2) <0

f_{av} - f_a = (4*a*k0^3 + 4*c*k0^3 - 2*a*b^2*k0^3 - 2*a*b*k0^3 + 2*b*c*k0^3 + 8*a*dkav*k0^2 + 4*a*dkav^2*k0 + 4*a*dkav*l^2 + 4*a*dkav^2*l + 8*c*dkav*k0^2 + 4*c*dkav^2*k0 + 4*c*dkav*l^2 + 4*c*dkav^2*l + 4*a*k0*l^2 + 8*a*k0^2*l + 4*c*k0*l^2 + 8*c*k0^2*l - 4*a*b*dkav*k0^2 - 2*a*b*dkav^2*k0 + 4*b*c*dkav*k0^2 + 2*b*c*dkav^2*k0 - 2*a*b*k0^2*l + 2*b*c*k0^2*l - 4*c*dkav*k0^2*s - 4*c*dkav^2*k0*s - 4*c*dkav*l^2*s - 4*c*dkav^2*l*s - 4*a*b^2*dkav*k0^2 - 2*a*b^2*dkav^2*k0 + 12*a*dkav*k0*l + 12*c*dkav*k0*l + b^2*c*dkav*k0^2*s + b^2*c*dkav^2*k0*s - 2*a*b*dkav*k0*l + 2*b*c*dkav*k0*l - 8*c*dkav*k0*l*s)/((2*dkav + 2*k0 - dkav*s)*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)) - (2*a*k0^2 + 2*a*l^2 + 2*c*k0^2 + 2*c*l^2 - a*b^2*k0^2 + 2*a*dka*k0 + 2*a*dka*l + 2*c*dka*k0 + 2*c*dka*l + 4*a*k0*l + 4*c*k0*l - a*b*k0^2 + b*c*k0^2 - a*b^2*dka*k0 - a*b*dka*k0 + b*c*dka*k0 - a*b*k0*l + b*c*k0*l)/(- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l) >0

f_{bv} - f_b = (2*b*l*(k0 + l)*(a - c)*(dka - dkav)*(2*k0 + 2*l + b*k0))/((- b^2*k0^2 - dka*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dka*k0 + 4*l^2 + 4*dka*l)*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)) <0

$\frac{\partial SW_{av}}{s}$=(4*dkav*(dkav + k0)^2*(k0 + l)*(a - c)^2*(- b^2*k0^2 - dkav*b^2*k0 - b*k0^2 - b*k0*l - dkav*b*k0 + 2*k0^2 + 4*k0*l + 2*dkav*k0 + 2*l^2 + 2*dkav*l)^2)/(3*(2*dkav + 2*k0 - dkav*s)^2*(- b^2*k0^2 - dkav*b^2*k0 + 4*k0^2 + 8*k0*l + 4*dkav*k0 + 4*l^2 + 4*dkav*l)^2*(- b^2*k0^2 - dkav*b^2*k0 + k0^2 + 2*k0*l + dkav*k0 + l^2 + dkav*l)) >0

Q_{av}-Q_a=((k0 + l)*(a - c)*(3*b^5*dka*dkav^2*k0^3*l - 2*b^6*dka^2*dkav*k0^4 - b^6*dka^2*k0^5 - 2*b^6*dka*dkav^2*k0^4 - 4*b^6*dka*dkav*k0^5 - 2*b^6*dka*k0^6 - b^6*dkav^2*k0^5 - 2*b^6*dkav*k0^6 - b^6*k0^7 - b^5*dka^2*dkav^2*k0^3 -

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2*b^5*dka^2*dkav*k0^4 - 4*b^5*dka^2*dkav*k0^3*l - b^5*dka^2*k0^5 -
4*b^5*dka^2*k0^4*l - 2*b^5*dka*dkav^2*k0^4 - b^6*dka^2*dkav^2*k0^3 -
4*b^5*dka*dkav*k0^5 - 2*b^5*dka*dkav*k0^4*l - 2*b^5*dka*k0^6 - 5*b^5*dka*k0^5*l -
b^5*dkav^2*k0^5 + 3*b^5*dkav^2*k0^4*l - 2*b^5*dkav*k0^6 + 2*b^5*dkav*k0^5*l -
b^5*k0^7 - b^5*k0^6*l + 7*b^4*dka^2*dkav^2*k0^3 + 7*b^4*dka^2*dkav^2*k0^2*l +
14*b^4*dka^2*dkav*k0^4 + 7*b^4*dka^2*dkav*k0^3*l - 7*b^4*dka^2*dkav*k0^2*l^2 +
7*b^4*dka^2*k0^5 - 7*b^4*dka^2*k0^3*l^2 + 14*b^4*dka*dkav^2*k0^4 +
28*b^4*dka*dkav^2*k0^3*l + 14*b^4*dka*dkav^2*k0^2*l^2 + 28*b^4*dka*dkav*k0^5 +
42*b^4*dka*dkav*k0^4*l + 14*b^4*dka*dkav*k0^3*l^2 + 14*b^4*dka*k0^6 +
14*b^4*dka*k0^5*l + 7*b^4*dkav^2*k0^5 + 21*b^4*dkav^2*k0^4*l +
14*b^4*dkav^2*k0^3*l^2 + 14*b^4*dkav*k0^6 + 35*b^4*dkav*k0^5*l +
21*b^4*dkav*k0^4*l^2 + 7*b^4*k0^7 + 14*b^4*k0^6*l + 7*b^4*k0^5*l^2 +
5*b^3*dka^2*dkav^2*k0^3 + 5*b^3*dka^2*dkav^2*k0^2*l + 10*b^3*dka^2*dkav*k0^4 +
15*b^3*dka^2*dkav*k0^3*l + 5*b^3*dka^2*dkav*k0^2*l^2 + 5*b^3*dka^2*k0^5 +
10*b^3*dka^2*k0^4*l + 5*b^3*dka^2*k0^3*l^2 + 10*b^3*dka*dkav^2*k0^4 +
15*b^3*dka*dkav^2*k0^3*l + 5*b^3*dka*dkav^2*k0^2*l^2 + 20*b^3*dka*dkav*k0^5 +
40*b^3*dka*dkav*k0^4*l + 25*b^3*dka*dkav*k0^3*l^2 + 5*b^3*dka*dkav*k0^2*l^3 +
10*b^3*dka*k0^6 + 25*b^3*dka*k0^5*l + 20*b^3*dka*k0^4*l^2 + 5*b^3*dka*k0^3*l^3 +
5*b^3*dkav^2*k0^5 + 10*b^3*dkav^2*k0^4*l + 5*b^3*dkav^2*k0^3*l^2 +
10*b^3*dkav*k0^6 + 25*b^3*dkav*k0^5*l + 20*b^3*dkav*k0^4*l^2 + 5*b^3*dkav*k0^3*l^3 +
5*b^3*k0^7 + 15*b^3*k0^6*l + 15*b^3*k0^5*l^2 + 5*b^3*k0^4*l^3 -
14*b^2*dka^2*dkav^2*k0^3 - 28*b^2*dka^2*dkav^2*k0^2*l - 14*b^2*dka^2*dkav^2*k0*l^2
- 28*b^2*dka^2*dkav*k0^4 - 42*b^2*dka^2*dkav*k0^3*l + 14*b^2*dka^2*dkav*k0*l^3 -
14*b^2*dka^2*k0^5 - 14*b^2*dka^2*k0^4*l + 26*b^2*dka^2*k0^3*l^2 +
38*b^2*dka^2*k0^2*l^3 + 12*b^2*dka^2*k0*l^4 - 28*b^2*dka*dkav^2*k0^4 -
98*b^2*dka*dkav^2*k0^3*l - 112*b^2*dka*dkav^2*k0^2*l^2 - 42*b^2*dka*dkav^2*k0*l^3 -
56*b^2*dka*dkav*k0^5 - 168*b^2*dka*dkav*k0^4*l - 178*b^2*dka*dkav*k0^3*l^2 -
76*b^2*dka*dkav*k0^2*l^3 - 10*b^2*dka*dkav*k0*l^4 - 28*b^2*dka*k0^6 -
70*b^2*dka*k0^5*l - 42*b^2*dka*k0^4*l^2 + 14*b^2*dka*k0^3*l^3 + 14*b^2*dka*k0^2*l^4
- 14*b^2*dkav^2*k0^5 - 70*b^2*dkav^2*k0^4*l - 114*b^2*dkav^2*k0^3*l^2 -
74*b^2*dkav^2*k0^2*l^3 - 16*b^2*dkav^2*k0*l^4 - 28*b^2*dkav*k0^6 -
126*b^2*dkav*k0^5*l - 210*b^2*dkav*k0^4*l^2 - 154*b^2*dkav*k0^3*l^3 -
42*b^2*dkav*k0^2*l^4 - 14*b^2*k0^7 - 56*b^2*k0^6*l - 84*b^2*k0^5*l^2 - 56*b^2*k0^4*l^3
- 14*b^2*k0^3*l^4 - 4*b*dka^2*dkav^2*k0^3 - 8*b*dka^2*dkav^2*k0^2*l -
4*b*dka^2*dkav^2*k0*l^2 - 8*b*dka^2*dkav*k0^4 - 8*b*dka^2*dkav*k0^3*l +
8*b*dka^2*dkav*k0^2*l^2 + 8*b*dka^2*dkav*k0*l^3 - 4*b*dka^2*k0^5 +
24*b*dka^2*k0^3*l^2 + 32*b*dka^2*k0^2*l^3 + 12*b*dka^2*k0*l^4 - 8*b*dka*dkav^2*k0^4
- 36*b*dka*dkav^2*k0^3*l - 48*b*dka*dkav^2*k0^2*l^2 - 20*b*dka*dkav^2*k0*l^3 -
16*b*dka*dkav*k0^5 - 56*b*dka*dkav*k0^4*l - 72*b*dka*dkav*k0^3*l^2 -
40*b*dka*dkav*k0^2*l^3 - 8*b*dka*dkav*k0*l^4 - 8*b*dka*k0^6 - 20*b*dka*k0^5*l +
40*b*dka*k0^3*l^3 + 40*b*dka*k0^2*l^4 + 12*b*dka*k0*l^5 - 4*b*dkav^2*k0^5 -
28*b*dkav^2*k0^4*l - 60*b*dkav^2*k0^3*l^2 - 52*b*dkav^2*k0^2*l^3 - 16*b*dkav^2*k0*l^4
- 8*b*dkav*k0^6 - 48*b*dkav*k0^5*l - 112*b*dkav*k0^4*l^2 - 128*b*dkav*k0^3*l^3 -
72*b*dkav*k0^2*l^4 - 16*b*dkav*k0*l^5 - 4*b*k0^7 - 20*b*k0^6*l - 40*b*k0^5*l^2 -
40*b*k0^4*l^3 - 20*b*k0^3*l^4 - 4*b*k0^2*l^5 + 8*dka^2*dkav^2*k0^3 +
24*dka^2*dkav^2*k0^2*l + 24*dka^2*dkav^2*k0*l^2 + 8*dka^2*dkav^2*l^3 +
16*dka^2*dkav*k0^4 + 32*dka^2*dkav*k0^3*l - 32*dka^2*dkav*k0*l^3 - 16*dka^2*dkav*l^4
```

+ 8*dka^2*k0^5 + 8*dka^2*k0^4*l - 48*dka^2*k0^3*l^2 - 112*dka^2*k0^2*l^3 - 88*dka^2*k0*l^4 - 24*dka^2*l^5 + 16*dka*dkav^2*k0^4 + 88*dka*dkav^2*k0^3*l + 168*dka*dkav^2*k0^2*l^2 + 136*dka*dkav^2*k0*l^3 + 40*dka*dkav^2*l^4 + 32*dka*dkav*k0^5 + 144*dka*dkav*k0^4*l + 256*dka*dkav*k0^3*l^2 + 224*dka*dkav*k0^2*l^3 + 96*dka*dkav*k0*l^4 + 16*dka*dkav*l^5 + 16*dka*k0^6 + 56*dka*k0^5*l + 40*dka*k0^4*l^2 - 80*dka*k0^3*l^3 - 160*dka*k0^2*l^4 - 104*dka*k0*l^5 - 24*dka*l^6 + 8*dkav^2*k0^5 + 64*dkav^2*k0^4*l + 176*dkav^2*k0^3*l^2 + 224*dkav^2*k0^2*l^3 + 136*dkav^2*k0*l^4 + 32*dkav^2*l^5 + 16*dkav*k0^6 + 112*dkav*k0^5*l + 320*dkav*k0^4*l^2 + 480*dkav*k0^3*l^3 + 400*dkav*k0^2*l^4 + 176*dkav*k0*l^5 + 32*dkav*l^6 + 8*k0^7 + 48*k0^6*l + 120*k0^5*l^2 + 160*k0^4*l^3 + 120*k0^3*l^4 + 48*k0^2*l^5 + 8*k0*l^6))/(6*(b^4*dka^2*k0^2 + 2*b^4*dka*k0^3 + b^4*k0^4 - 5*b^2*dka^2*k0^2 - 5*b^2*dka^2*k0*l - 10*b^2*dka*k0^3 - 15*b^2*dka*k0^2*l - 5*b^2*dka*k0*l^2 - 5*b^2*k0^4 - 10*b^2*k0^3*l - 5*b^2*k0^2*l^2 + 4*dka^2*k0^2 + 8*dka^2*k0*l + 4*dka^2*l^2 + 8*dka*k0^3 + 24*dka*k0^2*l + 24*dka*k0*l^2 + 8*dka*l^3 + 4*k0^4 + 16*k0^3*l + 24*k0^2*l^2 + 16*k0*l^3 + 4*l^4)*(b^4*dkav^2*k0^2 + 2*b^4*dkav*k0^3 + b^4*k0^4 - 5*b^2*dkav^2*k0^2 - 5*b^2*dkav^2*k0*l - 10*b^2*dkav*k0^3 - 15*b^2*dkav*k0^2*l - 5*b^2*dkav*k0*l^2 - 5*b^2*k0^4 - 10*b^2*k0^3*l - 5*b^2*k0^2*l^2 + 4*dkav^2*k0^2 + 8*dkav^2*k0*l + 4*dkav^2*l^2 + 8*dkav*k0^3 + 24*dkav*k0^2*l + 24*dkav*k0*l^2 + 8*dkav*l^3 + 4*k0^4 + 16*k0^3*l + 24*k0^2*l^2 + 16*k0*l^3 + 4*l^4)) >0

Q_{bv}-Q_b no confirmed answer

References

Álvarez-SanJaime, Ó., Cantos-Sánchez, P., Moner-Colonques, R. and Sempere-Monerris, J.J., 2013. Vertical integration and exclusivities in maritime freight transport. *Transportation Research Part E: Logistics and Transportation Review*, *51*, pp.50-61.

Asgari, N., Farahani, R.Z. and Goh, M., 2013. Network design approach for hub ports-shipping companies competition and cooperation. *Transportation Research Part A: Policy and Practice*, *48*, pp.1-18.

Baltazar, R. and Brooks, M.R., 2001, July. The governance of port devolution: A tale of two countries. In *World conference on transport research* (pp. 22-27).

Barbot, C. 2009. Airport and Airlines Competition: Incentives for Vertical Collusion. *Transportation Research Part B* 43

Barbot, C., T. D'Alfonso, P. Malighetti, and R. Redondi. 2013. Vertical Collusion between Airports and Airlines: An Empirical Test for the European Case. *Transportation Research Part E*, 57, pp.3–15.

Blois, K.J., 1972. Vertical quasi-integration. *The Journal of Industrial Economics*, pp.253-272.

Cantos, P., Pastor, J.M. and Serrano, L., 2012. Evaluating European railway deregulation using different approaches. *Transport Policy*, *24*, pp.67-72.

Chipty, T., 2001. Vertical integration, market foreclosure, and consumer welfare in the cable television industry. *American Economic Review*, *91*(3), pp.428-453.

Cui, H. and Notteboom, T., 2017. Modelling emission control taxes in port areas and port privatization levels in port competition and co-operation sub-games. *Transportation Research Part D: Transport and Environment*, *56*, pp.110-128.

Cullinane, K. and Song, D.W., 2002. Port privatization policy and practice. *Transport Reviews*, *22*(1), pp.55-75.

Cullinane, K., Song, D.W. and Wang, T., 2005. The application of mathematical programming approaches to estimating container port production efficiency. *Journal of productivity analysis*, *24*(1), pp.73-92.

Czerny, A., Höffler, F. and Mun, S.I., 2014. Hub port competition and welfare effects of strategic privatization. *Economics of Transportation*, *3*(3), pp.211-220.

D'Alfonso, T., and A. Nastasi. 2012. Vertical Relations in the Air Transport Industry: A Facility-Rivalry Game. *Transportation Research Part E,* 48 (5), pp. 993–1008.

De Borger, B. and De Bruyne, D., 2011. Port activities, hinterland congestion, and optimal government policies the role of vertical integration in logistic operations. *Journal of Transport Economics and Policy (JTEP)*, *45*(2), pp.247-275.

De Borger, B. and Fosgerau, M., 2008. The trade-off between money and travel time: A test of the theory of reference-dependent preferences. *Journal of urban economics*, *64*(1), pp.101-115.

de Souza Junior, G.A., Beresford, A.K. and Pettit, S.J., 2003. Liner shipping companies and terminal operators: internationalisation or globalisation?. *Maritime Economics & Logistics*, *5*(4), pp.393-412.

Forbes, S.J. and Lederman, M., 2010. Does vertical integration affect firm performance? Evidence from the airline industry. *The RAND Journal of Economics*, *41*(4), pp.765-790.

Franc, P. and Van der Horst, M., 2010. Understanding hinterland service integration by shipping lines and terminal operators: a theoretical and empirical analysis. *Journal of transport geography*, *18*(4), pp.557-566.

Fu, X., Homsombat, W. and Oum, T.H., 2011. Airport–airline vertical relationships, their effects and regulatory policy implications. *Journal of Air Transport Management*, *17*(6), pp.347-353.

Gal-Or, E., 1992. Vertical integration in oligopoly. *JL Econ. & Org., 8*, p.377.

Growitsch, Christian, and Heike Wetzel. 2009. “Testing for Economies Of Scope in European Railways: an Efficiency Analysis.” *Journal Of Transport Economics and Policy* 43 (1): 1-24.

Guo, C. and Wang, J., 2009. Research on Competition and Cooperation Mechanism Between the Port and Shipping Company. In *Logistics: The Emerging Frontiers of Transportation and Development in China* (pp. 396-402).

Haralambides, H.E., 2002. Competition, excess capacity, and the pricing of port infrastructure. *International journal of maritime economics*, *4*(4), pp.323-347.

Haralambides, H.E., Cariou, P. and Benacchio, M., 2002. Costs, benefits and pricing of dedicated container terminals. *International Journal of Maritime Economics*, *4*(1), pp.21-34.

Heaver, T., Meersman, H. and Van de Voorde, E., 2001. Co-operation and competition in international container transport: strategies for ports. *Maritime Policy & Management*, *28*(3), pp.293-305.

Imai, A., Sasaki, K., Nishimura, E. and Papadimitriou, S., 2006. Multi-objective simultaneous stowage and load planning for a container ship with container rehandle in yard stacks. *European Journal of Operational Research*, *171*(2), pp.373-389.

Jiang, C., Fu, X., Ge, Y.E., Zhu, S., Zheng, S. and Xiao, Y.B., 2021. Vertical integration and capacity investment in a two-port system. *Transportmetrica A: Transport Science*, *17*(4), pp.1431-1459.

Kaselimi, E.N., Notteboom, T.E. and De Borger, B., 2011. A game theoretical approach to competition between multi-user terminals: the impact of dedicated terminals. *Maritime Policy & Management*, *38*(4), pp.395-414.

Ksoll, M., 2004, October. Integration of infrastructure and transport: An assessment from industrial economics and railway perspectives. In *2nd Conference on Railroad Industry Structure, Competition and Investment* (pp. 8-9).

Lee, C.B., Wan, J., Shi, W. and Li, K., 2014. A cross-country study of competitiveness of the shipping industry. *Transport Policy*, *35*, pp.366-376.

Matsushima, N. and Takauchi, K., 2014. Port privatization in an international oligopoly. *Transportation Research Part B: Methodological*, *67*, pp.382-397.

Merk, O. and Teodoro, A., 2022, July. Performance of Maritime Logistics. *International Transport Forum*.

Midoro, R., Musso, E. and Parola*, F., 2005. Maritime liner shipping and the stevedoring industry: market structure and competition strategies. *Maritime Policy & Management*, *32*(2), pp.89-106.

Notteboom, T. and Rodrigue, J.P., 2012. The corporate geography of global container terminal operators. *Maritime Policy & Management*, *39*(3), pp.249-279.

Notteboom, T.E., Parola, F., Satta, G. and Pallis, A.A., 2017. The relationship between port choice and terminal involvement of alliance members in container shipping. *Journal of Transport Geography*, *64*, pp.158-173.

Pagano, A.M., Wang, G.W., Sánchez, O.V. and Ungo, R., 2013. Impact of privatization on port efficiency and effectiveness: results from Panama and US ports. *Maritime Policy & Management*, *40*(2), pp.100-115.

Paridaens, H., & Notteboom, T. (2022). Logistics integration strategies in container shipping: A multiple case-study on Maersk Line, MSC and CMA CGM. *Research in Transportation Business & Management*, *45*, 100868.

Parola, F., Satta, G. and Caschili, S., 2014. Unveiling co-operative networks and ‘hidden families’ in the container port industry. *Maritime Policy & Management*, *41*(4), pp.384-404.

Preston, J. 1996. “The Economics of British Rail Privatization: An Assessment.” *Transport Reviews* 16 (1): 1–21.

Reynaerts, J., 2010. Simulating mergers between stevedores. *Maritime Economics & Logistics*, *12*(1), pp.8-35.

Riordan, M.H., 1998. Anticompetitive vertical integration by a dominant firm. *American Economic Review*, pp.1232-1248.

Rodrigue, J.P. and Notteboom, T., 2009. The terminalization of supply chains: reassessing the role of terminals in port/hinterland logistical relationships. *Maritime Policy & Management*, *36*(2), pp.165-183.

Rodrigue, J.P. and Notteboom, T., 2010. Foreland-based regionalization: Integrating intermediate hubs with port hinterlands. *Research in Transportation Economics*, *27*(1), pp.19-29.

Saraswati, B., and S. Hanaoka. 2014. Airport–Airline Cooperation under Commercial Revenue Sharing Agreements: A Network Approach. *Transportation Research Part E* 70, pp. 17–33.

Slack, B., 1993. Pawns in the game: ports in a global transportation system. *Growth and change*, *24*(4), pp.579-588.

Soppé, M., Parola, F. and Frémont, A., 2009. Emerging inter-industry partnerships between shipping lines and stevedores: from rivalry to cooperation? *Journal of Transport Geography*, *17*(1), pp.10-20.

Spengler, J.J., 1950. Vertical integration and antitrust policy. *Journal of political economy*, *58*(4), pp.347-352.

Tongzon, J. and Heng, W., 2005. Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). *Transportation Research Part A: Policy and Practice*, *39*(5), pp.405-424.

Van de Voorde, E. and Vanelslander, T., 2010. Market power and vertical and horizontal integration in the maritime shipping and port industry.

Van Reeven, P., 2010. The effect of competition on economic rents in seaports. *Journal of Transport Economics and Policy (JTEP)*, *44*(1), pp.79-92.

Xiao, Y., Ng, A.K., Yang, H. and Fu, X., 2012. An analysis of the dynamics of ownership, capacity investments and pricing structure of ports. *Transport Reviews*, *32*(5), pp.629-652.

Yang, D., Li, L., & Notteboom, T. (2022). Chinese investment in overseas container terminals: The role of investor attributes in achieving a higher port competitiveness. *Transport Policy*, *118*, 112-122.

Yang, H., A. Zhang, and X. Fu. 2015. Determinants of Airport–Airline Vertical Arrangements: Analytical Results and Empirical Evidence. *Journal of Transport Economics and Policy* 49 (3): 438–453.

Ye, Q., Xu, Z. and Fang, D., 2012. Market structure, performance, and efficiency of the Chinese banking sector. *Economic Change and Restructuring*, *45*, pp.337-358.

Yip, T.L., Liu, J.J., Fu, X. and Feng, J., 2014. Modeling the effects of competition on seaport terminal awarding. *Transport Policy, 35*, pp.341-349.

Zaheer, A. and Venkatraman, N., 1995. Relational governance as an interorganizational strategy: An empirical test of the role of trust in economic exchange. *Strategic management journal*, *16*(5), pp.373-392.

Zhang, A., X. Fu, and H. Yang. 2010. Revenue Sharing with Multiple Airlines and Airports. *Transportation Research Part B* 44 (8): 944–959.

Zhu, S., Zheng, S., Ge, Y.E., Fu, X., Sampaio, B. and Jiang, C., 2019. Vertical integration and its implications to port expansion. *Maritime Policy & Management*, *46*(8), pp.920-938.

Zondag, B., Bucci, P., Gützkow, P. and de Jong, G., 2010. Port competition modeling including maritime, port, and hinterland characteristics. *Maritime Policy & Management*, *37*(3), pp.179-194.

Chapter 5 Modelling emission control taxes in port areas and port privatization levels in port competition and co-operation sub-games [3]

Abstract

Using a game theory approach, this paper analyses a situation in which the government imposes a certain emission tax on vessels and port operations for emission control in port areas. Two ports are considered: a purely private port and a landlord (partial public) port. These two ports are in Cournot or Bertrand competition or cooperation with differentiated service. Our model outcomes lead to the following conclusions. First, the optimal private level of port 2 under Cournot and Bertrand competition varies between fully private and highly public concerned port, while the government will prefer a highly public concerned or close to highly public concerned port in the cooperation scenario. Second, the government will have to make stricter efforts to enhance environmental protection in the situation of port cooperation (monopoly) than in the case of inter-port competition, and all the optimal emission tax should always be lower than the marginal emission damage. Third, port privatization has a non-monotonous effect on ports` environmental damage in the inter-port competition scenarios and a monotonous decreasing effect in the cooperation scenario. Fourth, the total emission tax revenue is always higher than the overall environmental damage in the cooperative scenario, and it may or may not be able to cover the whole environmental damage in Cournot and Bertrand competitions. Finally, the government may face a trade-off among environmental protection, maximizing social welfare, and satisfying individual motivation when considering port cooperation (monopoly).

Keywords: *port privatization, emission tax, game theory, environmental damage, competition, cooperation*

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[3] This chapter is a slightly amended version of the published paper:
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5.1 Introduction

Maritime transport is the most environmentally friendly transport mode in terms of emission/fuel consumption per ton of cargo. However, due to its overwhelming share in international cargo shipments, it represents a significant share of global emissions, including GHGs, NO_x, and SO_2. According to the third IMO GHG study of 2014, international shipping emitted 796 million tons of CO2 in 2012, about 2.2% of total global CO2 emissions for that year, compared to 885 million tons in 2007, about 2.8% for that year. Ships emitted respectively 15% and 4%-9% of the global NO_x and SO_2 (Tzannatos, 2010). Zhou et al. (2020) conducted a survey on Shanghai port, showing that the annual emissions of nitrogen oxides, carbon monoxide, and carbon dioxide caused by cargo-handling equipment in 2015 were 1811, 1741, and 141805 tons, respectively. In April 2018 and during the session of MEPC72 (followed by the session of MEPC73), the International Maritime Organization pledged a 50% reduction of the shipping generated GHGs by the year 2050 when compared to the emission levels of 2008, with the intention to reduce more than 70% by the end of the century (IMO, MPEC, 2018). So, to cope with the challenges of emission reduction, the Carbon Intensity Indicator (CII) rating has been implemented since January 1, 2023, based on MARPOL Annex VI, aiming to measure and improve the performance of ships. A grading system based on the fleet`s 2019-2021 CII performance will guide the rating of CII under grade C and will result in a Ship Energy Efficiency Management Plan (SEEMP) remedial measure.

Compared to the overall emissions of the shipping industry, emissions in port areas are relatively small. Given the proximity of most ports to urbanized areas, the emissions in ports greatly impact port and contiguous community areas (Saxe et al., 2004; Dore et al., 2007). A study found that certain ship emissions in ports are estimated to be about ten times higher than the emissions from port operations (Habibi et al., 2009). The GHGs in the Barcelona port area were found to be equal to the GHGs emitted by land activities (Villalba et al., 2011). Emissions of NO_x and SO_2 in port areas are highly linked to regional air quality, given the impact of NO_x and SO_2 on acidification and NO_x on eutrophication and tropospheric ozone formation. They also affect public health and ecosystems (lung cancer, allergies, and asthma), particularly in coastal communities (Corbett et al., 1997; WHO, 2000; Eyring et al., 2010; Song, 2014).

In recent times, a number of ports run by local or central authorities have begun or are planning to implement programs or policies that address these pollution problems (Gibbs et al., 2014), either on ships or in ports. To reduce ship emissions, local authorities can set minimum technical standards for ships. This measure can include a compulsory fuel switch program (e.g., the use of low sulfur fuel and MDO) or the installation of emission control equipment on ships (e.g., scrubber). The port authorities of Rotterdam, Antwerp, Amsterdam, Le Havre, Hamburg, and Bremen, in cooperation with the International Association of Ports and Harbors (IAPH), have developed the Environmental Ship Index (ESI) to give scores ranging from 0 to 100 with 100 points corresponding to a zero-emission ship, where the concept of zero-emission ships migrates from fossil fuel-based propulsion systems, towards different hybrid and all-electric propulsion system concepts, integrating alternative fuels from renewable energy sources (RES) having low and zero-carbon content (Reusser et al., 2021). Vessels with a score above a certain threshold can be granted a discount on port dues in the participating ports of call (Lam and Notteboom, 2014). Such voluntary schemes are aimed at giving ship owners and ship operators a price incentive to invest in greener ship technology. While port users are rewarded for being greener, it is more important to assess whether the price incentive can cover the extra cost of being greener. To reduce the emissions related to port operations, many ports have the pressure of replacing fossil fuel-driven facilities/vehicles with electricity-powered or hybrid ones. For instance, the port of Long Beach implemented a green port policy to transit to renewable power sources and self-generation systems, thereby reducing diesel particulate emissions, nitrogen oxides, sulfur oxides, and greenhouse gases by 85%, 50%, 97%, and 21% respectively at the cost of approximately USD 500 million from 2005 to 2014.

These programs above result in a de facto rise in the cost of port calls due to various emission reduction investments. Given that pollution can be measured and traced (Villalba et al., 2011; Geerlings et al., 2011; Gibb et al., 2014), many studies have started to focus on emission taxes. Wang et al. (2009) first proposed the idea of charging emission taxes with pollution abatement measures. Tseng et al. (2016) proposed a ship emission tax in port/berth and considered it valuable and viable at a policy level. Zheng et al. (2017) investigated a possible port emission regulation impacted by incomplete information. Sheng et al. (2017) investigated the economic and environmental effects of a unilateral maritime emission regulation vs. a uniform maritime emission regulation. So, governments are able to directly design and implement environmental regulations by imposing emission control taxes on the polluters in the port area and using the proceeds to clean up the pollution effects (see Wang et al., 2009).

These measures/programs and the possible emission control taxes are expected to have an effect on port competitiveness and inter-port competition. For example, Notteboom (2006) found that switching from HFO to MGO will increase ship cost significantly due to the high bunker cost, so that, eventually, it will affect port competitiveness. Notteboom et al. (2011) also concluded that the compulsory use of low-sulfur fuel for RORO shipping in the Baltic and North Sea leads to increases in freight rates and a potential traffic loss/shift to road haulage (the so-called modal back shift). Wang et al. (2014) mentioned the influence of setting an Emission Control Area (ECA) in the Pearl River Delta and found that “fuel cost rise (due to setting ECA) may give a disadvantage to ports within the Pearl River Delta by suffering traffic loss…”. Tseng et al. (2016) referred to the concerns of port operators and the government on the negative impact of possible emission taxes on port traffic, especially considering the fierce inter-port competition in the region.

Figure 31 The existing emission control areas

Source: Ma et al., 2021

The authority above, including port authorities and municipal or central governments, are often the key (co-)initiators of the development of measures to lower emissions in ports and are heavily influenced by the port governance and ownership structure. Since the 1980s, port privatization has become increasingly common worldwide. Although the situation differs from port to port, according to the general category (ownership structure) defined by The World Bank (2007), service/tool (public) ports and landlord ports are generally considered to have a strong focus on public objectives (i.e., maximizing consumer surplus), while fully private ports will mainly focus on profits only. Generally, the higher the public/state-owned investment, the stronger the focus on the overall social welfare of the port since the investments from public sources must satisfy more diversified / combined objectives, e.g., even including indirect employment linked to the port. For instance, certain special public ports can be found in China. The container terminals in Shanghai are mainly owned and operated by Shanghai International Port Group (SIPG), whose top four shareholders are the Shanghai Supervision Committee of State-owned Assets (31.36%), Adroit Investments Limited (24.04%, an HK-based private company, a subsidy of China Merchants Port Holdings Company Limited, state level), Shanghai Tongsheng Investments Ltd (19.86%, a subsidiary of Shanghai Supervision Committee of State-owned Assets, municipal level) and Shanghai Chengtou Ltd (4.21%, a subsidiary of Shanghai Supervision Committee of State-owned Assets, municipal level). Its top objective (vision), as found on its official website, is to serve as the gateway port in the Yangtze River Delta and to keep its position as the world’s biggest container port in throughput terms, offering a diversified service. Meanwhile, the objectives of the state/municipal-owned investment companies, as its shareholders, are also to achieve a high ROI. In other words, its primary objective is to guarantee a certain threshold throughput (consumer surplus) and to generate enough spillover effects, followed by a second objective of high profitability. Similarly, landlord ports typically combine public and private objectives. For instance, the port of Antwerp in Belgium is a typical landlord port. The port authority owns and manages the sites in the port area and makes them available to port companies for their activities based on concession agreements. Its concession policy is aimed at keeping a balance between promoting sustainable development (i.e., the balance between public objectives and private objectives, e.g., throughput guarantee, gateway port function, attracting investment, profits, etc.) and making the most efficient use of the available land (i.e., related to the agreements with port operators about the profit allocation through concession). These two examples show that public ports and landlord ports both pursue differentiated public and private goals to satisfy their stakeholders. Compared to the public port/landlord port, a private port (i.e., owned and operated by a private port authority and/or private port operator) also shares certain public objectives, but its primary goal is mainly about creating profit for its mother company. A typical example of a fully private port is the port of Felixstowe, whose daily operations and infrastructure have been privatized since the 1990s and are wholly owned by Hutchison Port UK, a subsidiary of HPH group.

Table 15 The objectives of ports as a function of the main governance models

Port objectives	***Governance model***		***Some applications***	***Strengths***	***Weaknesses***
Mainly profit-driven objective	***Private Port***		New Zealand, Australia, United Kingdom	Flexibility, market-oriented	No vision for the community and local development
Combined public and private objectives	***Landlord***	***China model***	China	Central planning, Community and local development-	Rigidity, bureaucracy, scarce proactivity of

				oriented, joint venture development	the port authority
		Latin tradition	France, Italy, Spain	Community and local development-oriented PPP development	Rigidity, bureaucracy, scarce proactivity of the PA
		Hanseatic tradition	Belgium, Germany, The Netherlands	Community and local development-oriented, Flexibility, PPP development	Possibility of having a limited vision for the local development
	Tool Port		South Africa, China	Central planning, private involvement	Rigidity, absence of private partnerships (PPP), public financing
	Public Port		Ukraine, Israel, China	Central planning, coordination among various national ports	Not market oriented, rigidity, absence of PPP possibilities, heavy bureaucracy

Source: adapted from Ferrari et al. (2015)

At the policy level, many governments consider privatizing or corporatizing public ports as a policy option to raise the competitive position of their ports (Baltazar & Brooks, 2001; Midoro et al., 2005; Czerny et al., 2013; Chen et al., 2017). Xiao et al. (2012) and Matsushima et al. (2014) all investigated the effects of ports' ownership structure on port charges, investments, profits, and welfare using a game theory approach. Lee et al. (2017) discussed the endogenous choice of port ownership under either Bertrand or Cournot competition by developing a third-market model consisting of two exporting firms and one importing country. Cullinane et al. (2002; 2005), Tongzon et al. (2005), Pagano et al. (2013), Jinhwan et al. (2015), and Dasgupta et al. (2016) all found that port privatization has positive effects on cost-effectiveness and technical efficiency. In contrast, Kawasaki et al. (2020) explored the effects of "consolidation" and "privatization" between adjacent ports. They employed a multi-agent simulation model applied to a case study for Kobe and Osaka ports and concluded that consolidation has a larger impact than privatization with respect to cargo volume and total surplus.

Based on the above discussion, we argue that it is crucial for the government/port authority to understand the effect of setting a proper emission tax scheme together with the procedure of privatizing the port in the current situation of fierce port competition and potential cooperation. However, literature in maritime economics focuses on either the effects of port privatization or the effects of possible emission (or carbon) tax schemes, but not on both issues combined. The most related studies can be found outside the maritime research field, i.e., in environmental economics. Beladi et al. (2006) prove that privatization will have a negative effect on the environment, and thus, environmental quality should be managed by the public domain. Barcena-Ruiz et al. (2006) found that environmental taxes are lower in a mixed oligopoly than in a private one, and thus, environmental damage is greater under nationalization. Wang and Wang (2009) investigated the effect of product differentiation on environmental damage. Wang et al. (2009), Pal et al. (2015), and Xu et al. (2016) show the interaction between privatization and environmental damage. Sheng et al. (2017) studied and compared the impact of unilateral emission regulation and unified emission regulation on the environment by establishing a two-stage game model. They found that unilateral regulation may increase the total emissions of ports and ships, while unified regulation always reduces the total emissions. Pian et al. (2020) studied the global emission taxes and port privatization policies under international competition and showed that the coordination of global emission taxes before privatization choices can induce the equilibrium of the game to be globally optimal when the emission tax is relatively high. However, most previous environmental economics studies assume that the polluters are responsible for all the pollution with investment in abatement measures. In the case of emissions in port areas, ports and ships are both responsible for environmental damage and the investment in emission reduction measures. In addition, previous studies only focused on the competition scenarios and did not consider a cooperation scenario.

In this paper, we model the interaction between emission control tax and port privatization in the context of port competition and cooperation. The model is based on a mixed duopoly with differentiated service, using a game theory approach to model port competition/cooperation given different settings on emission taxes in port areas and port privatization levels while also considering the share of emissions related to port operations in total port emissions. We compare the equilibrium statuses where a private port competes or cooperates with a partial public port with differentiated service in Cournot, Bertrand, and cooperation scenarios. In practice, Cournot competition is rare since two ports may not adjust their capacities at the same time. Bertrand competition is quite common and occurs where two ports are competing on price with stable capacity, e.g., in the case of the port of Hong Kong (a highly private but landlord port) competing with the port of Shenzhen (a partial public port). Port cooperation in this paper mainly refers to a port merger, where two ports form one single port authority and re-allocate port services among the two port areas. An example is Copenhagen-Malmo Port (CMP), which is the result of the merger between the port of Copenhagen in Denmark and the port of Malmo in Sweden.

The structure of this paper is as follows: after an introduction, a model of a mixed duopoly with differentiated service is presented, in which both emission tax and the port privatization level are considered. Then, we analyze two competition settings and a cooperation setting and find the optimal emission tax and port privatization level, respectively. Then, the equilibriums in each setting are compared to provide several policy implications in the concluding section.

5.2 Model specification

Consider a mixed duopoly with differentiated service between a fully private port 1 and a partial public port 2 (landlord port). The inverse demand function of the port-specific transport chain can be written as follows:

$$p_1 = a - q_1 - b * q_2 \tag{1}$$

$$p_2 = a - q_2 - b * q_1 \tag{2}$$

where q_1 and q_2, p_1 and p_2 denote the cargo volumes in the port-specific transport chains and the ports' service prices, respectively. **a** is the maximal reservation service price. **b** is considered as the inverse of the service differentiation level (i.e., the level of service similarity). The concept of service differentiation is documented extensively in microeconomic theory. From a neoclassical perspective, it can be argued that two load centers in the same multi-port gateway region are perfect substitutes for a port user if that user is willing to substitute one load center for another at a constant rate (Notteboom, 2009). The most used method to analyze service differentiation is by checking the cross-price elasticity between ports. This approach has been used in a number of port pricing studies (Haralambides et al., 2002). Notteboom (2009) proposed an alternative approach to determine the service differentiation level by analyzing the revealed preference of container port users (i.e., shipping lines) in terms of demand profile (scale and growth, foreland & hinterland orientation), supply profile (Room for expansion, location, and nautical access) and market profile (market structure terminal operating business, cargo control, distribution activity in port). In this study, we apply the demand curve-price elasticity for simplification. We have $b \in (0,1)$, implying that when b is close to 1, the two ports are highly substitutable.

Port 1 is a profit-seeking port, which is only trying to maximize its own aggregated profit, while Port 2 is a partial public port aimed at maximizing a combined goal of public and private objectives. The private objective is captured by profits. The consumer surplus is used as a proxy for the public objective.

The consumer surplus (CS) can be obtained from the demand function:

$$CS = 0.5 * (q_1^2 + q_2^2 + 2 * b * q_1 * q_2) \tag{3}$$

For the cost function, we assume both ports have a similar technology level with an identical average marginal cost **c** per TEU, so the cost structure for each port is:

$$total\ cost = c * q_i + F$$

Where i=1, 2 and F represent the fixed cost, and making F=0 without losing generality, and it is assumed that $a - c - n * t > 0, n \in (0,1)$, where **t** is the emission control tax per TEU. This assumption also implies that the average cost per TEU plus emission control tax should never surpass the maximal reservation service price.

Following Xu. et al. (2016), we assume the initial total emissions from ports and ships in the port areas are equal to the quantity of service provided: q_1 and q_2. As we mentioned, the government will charge the emission control tax "**t**" based on the quantity of emissions, so both port areas will tend to reduce the total emissions by a_1 and a_2, respectively, which requires investments by the ship operators and port to meet technical requirements for emission reduction: ${a_1}^2/2$ and ${a_2}^2/2$. The above leads to the following actual total emissions in two port areas:

$$e_i = q_i - a_i, \text{ where i=1, 2.} \tag{4}$$

Based on the actual emissions, both port areas (both port and ship operators) have to pay emission taxes for the pollution they cause at the rate of **t** per TEU. We assume that the emissions caused by port operations account for $\boldsymbol{n * e_i}, where\ i = 1,2, n \in (0,1)$ of total port emissions respectively, and instinctively, both ports are responsible for that part of the investment for emission reduction: $\boldsymbol{n * a_i^2/2}, where\ i = 1,2, n \in (0,1)$. The environmental damage (ED) of both port areas is formulated as a function of their actual emissions:

$$ED = (e_1 + e_2)^2/2 \tag{5}$$

The emission tax revenue is obtained by the government from ship operators and port operators. It is defined in terms of the actual emission quantity: $emission\ tax\ revenue_i = t * e_i$, where i=1, 2.

So, the total emission tax (revenue) is the sum of both port areas` total emission tax revenues:

$$total\ emission\ tax = t * (e_1 + e_2) \tag{6}$$

For private port 1, the combined port objective is:

$$R_1 = (p_1 - c) * q_1 - n * t * e_1 - n * a_1^2/2 \tag{7}$$

This combined/aggregated objective contains that part of port 1`s investment in emission reduction and its emission tax, and the planned profit of the port. Meanwhile, the payoff of port 2 (G) consists of two parts: the public objective reflected by CS and the profit objective. Based on the model presented by Matsumura (1998), the weight of the private objective is introduced to combine both public and private objectives:

$$G = m * R_2 + (1 - m) * (R_2 + CS) \tag{8}$$

where $R_2 = (p_2 - c) * q_2 - n * t * e_2 - n * a_2^2/2$. Parameter $m \in (-0.25,1)$ defines the private involvement in port 2: if m=1, port 2 is a fully privatized port; if m=-0.25, port 2 is a fully public port. We have $baseline\ m = -0.25$ for simplification, and if m=-0.25, the objective function of port 2 will be: $G = R_2 + 1.25 * CS$.

The overall social welfare contains all the profits, consumer surplus, tax revenue minus environmental damage:

$$W = CS + R_1 + R_2 + total\ tax - ED \tag{9}$$

Noted that the social welfare of the port refers to an economic status that evaluates the impact of a port's operations, infrastructure, and policies on the overall well-being of society. Fraja and Delbono (1989) present social welfare as the summation of consumer surplus and the firms`s (ports`) profits.

The game in this paper is running as follows. In the first stage, the government will decide on the level of emission control tax: $\boldsymbol{t}$ and how much to privatize Port 2: $\boldsymbol{m}$, in order to maximize the social welfare. In the second stage, both ports will decide their abatement level: $\boldsymbol{a_1}$ and $\boldsymbol{a_2}$ and quantity/price: $\boldsymbol{p_1}$, $\boldsymbol{p_2}$, $\boldsymbol{q_1}$, $\boldsymbol{q_2}$ simultaneously in Cournot/Bertrand competition or cooperation settings to achieve their own objectives. The backward induction is applied to find the Nash equilibrium in various settings.

5.3 The equilibrium analysis of the sub-games

In this section, we investigate three possible scenarios for the two ports, including a Cournot (quantity) competition scenario, a Bertrand (price) competition scenario, and a strategic cooperation scenario.

5.3.1 Sub-game 1: Cournot competition between the two ports

Consider that both ports optimize their payoffs by adjusting the quantity of service. So, based on backward induction, both ports will firstly maximize their objectives (First order condition) in terms of q_1, q_2, and a_1, a_2: $\frac{\partial R_1}{\partial q_1} = \frac{\partial G}{\partial q_2} = 0$ and $\frac{\partial R_1}{\partial a_1} = \frac{\partial G}{\partial a_2} = 0$, then we get:

$$q_1 = -\frac{(m - b + 1)(c - a + nt)}{-mb^2 + 2m + 2} \tag{10}$$

$$q_2 = \frac{(bm-2)(c-a+nt)}{-mb^2+2m+2} \tag{11}$$

$$a_1 = a_2 = t \tag{12}$$

$$p_1 = a + \frac{(m-b+1)(c-a+nt)}{-mb^2+2m+2} - \frac{b(bm-2)(c-a+nt)}{-mb^2+2m+2} \tag{13}$$

$$p_2 = a - \frac{(bm-2)(c-a+nt)}{-mb^2+2m+2} + \frac{b(m-b+1)(c-a+nt)}{-mb^2+2m+2} \tag{14}$$

Based on the results, we conclude that privatizing the port has a negative influence on the cargo volume of Port 2, but positive influences on Port 1, $\frac{\partial q_1}{\partial m} > 0, \frac{\partial q_2}{\partial m} < 0$, and will shrink the overall cargo volume: $\frac{\partial (q_1+q_2)}{\partial m} < 0,$ while it will raise both ports' service prices, $\frac{\partial p_1}{\partial m} > 0, \frac{\partial p_2}{\partial m} > 0.$ The abatements by the ports are decided by the optimal emission t, $a_1 = a_2 = t.$ We also found that increasing the proportion of emissions linked to port operations in total port emissions leads to a decrease in both ports` cargo volumes but increases both port`s service prices: $\frac{\partial q_1}{\partial n} < 0, \frac{\partial q_2}{\partial n} < 0, \frac{\partial p_1}{\partial n} > 0, \frac{\partial p_2}{\partial n} > 0.$

When we substitute (10), (11), (12), (13), and (14) into the social welfare function (9), we can obtain *W(b,m,n,t)^{qq}* (see appendix for full formulation). In order to maximize *W(b,m,n,t)^{qq}*, the government will choose an optimal emission control tax t: $\frac{\partial W(b,m,n,t)^{qq}}{\partial t} = 0$, so that the optimal t meets the following equation:

$$t = \frac{\alpha}{\beta} \tag{15}$$

where

$$\begin{aligned} \alpha = -(\mathrm{a} - \mathrm{c})(&6\,\mathrm{b} - 24\,\mathrm{m} - 2\,\mathrm{n} + 12\,\mathrm{b\,m} + 8\,\mathrm{m\,n} + 6\,\mathrm{b\,m}^2 + 9\,\mathrm{b}^2\mathrm{m} - 3\,\mathrm{b}^3\mathrm{m} \\ &+ 2\,\mathrm{b}^2\mathrm{n} + 2\,\mathrm{m}^2\mathrm{n} - 6\,\mathrm{m}^2 + 3\,\mathrm{b}^2\mathrm{m}^2 - 3\,\mathrm{b}^3\mathrm{m}^2 - 2\,\mathrm{b}^2\mathrm{m}^2\mathrm{n} + 2\,\mathrm{b}^3\mathrm{m}^2\mathrm{n} \\ &+ 2\,\mathrm{b\,m\,n} - 2\,\mathrm{b\,m}^2\mathrm{n} - 6\,\mathrm{b}^2\mathrm{m\,n} - 18) \end{aligned}$$

$$\begin{aligned} \beta = 2\,(&-\mathrm{b}^4\mathrm{m}^2\mathrm{n} + 4\,\mathrm{b}^4\mathrm{m}^2 - \mathrm{b}^3\mathrm{m}^2\mathrm{n}^2 + 3\,\mathrm{b}^3\mathrm{m}^2\mathrm{n} + 3\,\mathrm{b}^3\mathrm{m\,n} + \mathrm{b}^2\mathrm{m}^2\mathrm{n}^2 + \mathrm{b}^2\mathrm{m}^2\mathrm{n} \\ &- 16\,\mathrm{b}^2\mathrm{m}^2 + 3\,\mathrm{b}^2\mathrm{m\,n}^2 - 5\,\mathrm{b}^2\mathrm{m\,n} - 16\,\mathrm{b}^2\mathrm{m} - \mathrm{b}^2\mathrm{n}^2 + \mathrm{b\,m}^2\mathrm{n}^2 - 6\,\mathrm{b\,m}^2\mathrm{n} \\ &- \mathrm{b\,m\,n}^2 - 12\,\mathrm{b\,m\,n} - 6\,\mathrm{b\,n} - \mathrm{m}^2\mathrm{n}^2 + 2\,\mathrm{m}^2\mathrm{n} + 16\,\mathrm{m}^2 - 4\,\mathrm{m\,n}^2 \\ &+ 16\,\mathrm{m\,n} + 32\,\mathrm{m} + \mathrm{n}^2 + 14\,\mathrm{n} + 16) \end{aligned}$$

Equation (15) shows that the privatization of the port reduces the optimal tax: $\frac{\partial t}{\partial m} < 0$ and increases the service similarity among the two ports while it also reduces the optimal emission tax: $\frac{\partial t}{\partial b} < 0.$

When we substitute (15) into (10) - (12) and then substitute the updated q_1, q_2, a_1, a_2 (the updated (10) -(12)) into (5), the expression for environment damage (ED) becomes as follows:

$$ED = \frac{\gamma}{\delta} \tag{16}$$

where:

$$\begin{aligned} \gamma = (a - c)^2(n + 1)^2(&16\,m - 4\,b + 11\,n - 8\,b\,m - 14\,b\,n + 18\,m\,n - 4\,b\,m^2 \\ &- 6\,b^2m + 2\,b^3m + 7\,b^2n + 3\,m^2n + 4\,m^2 - 2\,b^2m^2 + 2\,b^3m^2 \\ &+ b^2m^2n + 2\,b^3m^2n - 12\,b\,m\,n - 6\,b\,m^2n - 2\,b^3m\,n + 12)^2 \end{aligned}$$

$$\begin{aligned} \delta = 8\,(&-b^4m^2n + 4\,b^4m^2 - b^3m^2n^2 + 3\,b^3m^2n + 3\,b^3m\,n + b^2m^2n^2 + b^2m^2n \\ &- 16\,b^2m^2 + 3\,b^2m\,n^2 - 5\,b^2m\,n - 16\,b^2m - b^2n^2 + b\,m^2n^2 \\ &- 6\,b\,m^2n - b\,m\,n^2 - 12\,b\,m\,n - 6\,b\,n - m^2n^2 + 2\,m^2n + 16\,m^2 \\ &- 4\,m\,n^2 + 16\,m\,n + 32\,m + n^2 + 14\,n + 16)^2 \end{aligned}$$

We find that $\frac{\partial ED}{\partial m}$ is not monotonous, implying that the effect of privatizing Port 2 on total ED is non-monotonous, which is consistent with the findings of Pal et al. (2015) and Xu. et al. (2016), but different from the results of Wang et al. (2009). Privatizing the port will directly reduce the total quantity (due to $\frac{\partial(q_1+q_2)}{\partial m} < 0$), while the privatization of the port will also reduce the abatement quantity ($a_1 = a_2 = t, \frac{\partial t}{\partial m} < 0$). So, the effect of privatization on ED is non-monotonous and depends on which side dominates.

When we substitute (15) into (10) - (14) and then substitute the updated (10) - (14): q_1, q_2, p_1, p_2, a_1, a_2 into (9), the social welfare W can be obtained:

$$W = \frac{\epsilon}{\zeta} \tag{17}$$

where

$$\begin{aligned}\epsilon = -(a - c)^2(54\,b - 118\,m - 4\,n + 56\,b\,m + 16\,m\,n + 34\,b\,m^2 + 30\,b^2m \\ + 4\,b^2n + 4\,m^2n - 25\,b^2 - 25\,m^2 + 7\,b^2m^2 - 16\,b^3m^2 - 4\,b^2m^2n \\ + 4\,b^3m^2n + 4\,b\,m\,n - 4\,b\,m^2n - 12\,b^2m\,n - 65)\end{aligned}$$

$$\begin{aligned}\zeta = 4(4\,(-\,b^4m^2n + 4\,b^4m^2 - b^3m^2n^2 + 3\,b^3m^2n + 3\,b^3m\,n + b^2m^2n^2 + b^2m^2n \\ - 16\,b^2m^2 + 3\,b^2m\,n^2 - 5\,b^2m\,n - 16\,b^2m - b^2n^2 + b\,m^2n^2 \\ - 6\,b\,m^2n - b\,m\,n^2 - 12\,b\,m\,n - 6\,b\,n - m^2n^2 + 2\,m^2n + 16\,m^2 \\ - 4\,m\,n^2 + 16\,m\,n + 32\,m + n^2 + 14\,n + 16)\end{aligned}$$

By making $\frac{\partial W}{\partial m} = 0$ to maximize the social welfare, the optimal privatization level can be written as $m = -\frac{29\,b + 9\,n - 11\,b\,n + 4\,b^2n - 25\,b^2 - 6}{11\,b + 7\,n - 5\,b\,n + 15\,b^2 - 34}$. $\frac{\partial m}{\partial b}$ is not monotonous, while $\frac{\partial m}{\partial n}>0$, suggesting that the higher the proportion of emissions related to port operations, the higher the optimal private level of port 2.

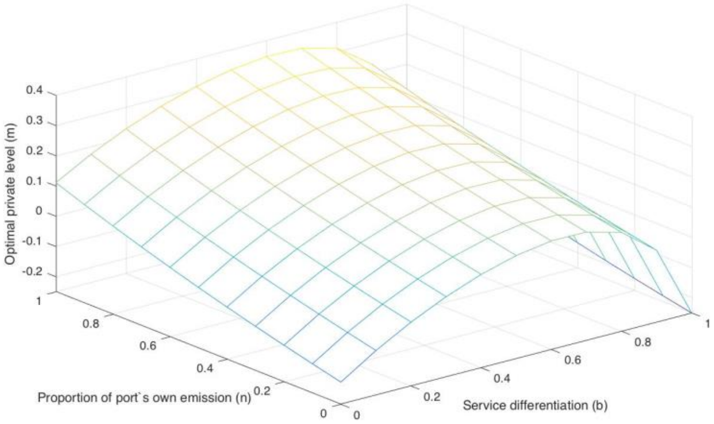

Figure 32 The optimal private level of port 2 in Cournot competition

Source: Author`s own elaboration.

Given the optimal m, the optimal emission control tax t equals:

$$t = -\frac{(a - c)(15\,b + 5\,n - 4\,b\,n - 18)}{4\,b^2n - 25\,b^2 + 4\,b\,n^2 - 22\,b\,n + 4\,b - 5\,n^2 + 20\,n + 28} \tag{18}$$

We found that $\frac{\partial t}{\partial b}$ is non-monotonous, like a U shape.

The optimal social welfare (W^{qq}), consumer surplus (CS^{qq}), environment damage (ED^{qq}), total emission tax^{qq}, profit of port 1 (R_1^{qq}), the revenue of port 2 (G^{qq}), q_1^{qq}, q_2^{qq}, and p_1^{qq}, p_2^{qq} can be found in the appendix.

5.3.2 Sub-game 2: Bertrand competition between the two ports

Consider that both ports optimize their payoffs by adjusting the service prices. Firstly, convert the inverse demand function (1), (2) into:

$$q_1 = \frac{a-ab+bp_2-p_1}{1-b^2} \tag{19}$$

$$q_2 = \frac{a-ab+bp_1-p_2}{1-b^2} \tag{20}$$

Substitution of (19), (20) into (7), (8) leads to the updated R_1 and G:

$$R_1 = \frac{c\,(a - p_1 - a\,b + b\,p_2)}{b^2 - 1} - \frac{a_1^2 n}{2} - \frac{p_1\,(a - p_1 - a\,b + b\,p_2)}{b^2 - 1} + n\,t\left(a_1 + \frac{a - p_1 - a\,b + b\,p_2}{b^2 - 1}\right) \tag{21}$$

$$G = (2\,a\,c + 2\,a\,p_1 - 2\,c\,p_2 + 2\,a^2 b + 2\,a^2 m + a_2^2 n + m\,p_1^2 + m\,p_2^2 - 2\,a^2 - p_1^2 + p_2^2 - a_2^2 b^2 n - 2\,a\,b\,c - 2\,a\,b\,p_1 + 2\,b\,c\,p_1 - 2\,a\,m\,p_1 - 2\,a\,m\,p_2 + 2\,a\,n\,t - 2\,a_2\,n\,t - 2\,n\,p_2\,t - 2\,a^2 b\,m - 2\,a\,b\,n\,t - 2\,b\,m\,p_1\,p_2 + 2\,b\,n\,p_1\,t + 2\,a_2\,b^2 n\,t + 2\,a\,b\,m\,p_1 + 2\,a\,b\,m\,p_2)/2\,(b^2 - 1) \tag{22}$$

Based on backward induction, both ports and ship operators will maximize their own objectives in terms of p_1, p_2 and a_1, a_2, $\frac{\partial R_1}{\partial p_1} = \frac{\partial G}{\partial p_2} = 0$ and $\frac{\partial R_1}{\partial a_1} = \frac{\partial G}{\partial a_2} = 0$, so we get:

$$p_1 = \frac{a + c - a\,b + b\,c + a\,m + c\,m + n\,t + b\,n\,t + m\,n\,t - a\,b^2 m}{-m\,b^2 + 2\,m + 2} \tag{23}$$

$$p_2 = \frac{2\,c + 2\,a\,m + 2\,n\,t - a\,b\,m + b\,c\,m - a\,b^2 m + b\,m\,n\,t}{-m\,b^2 + 2\,m + 2} \tag{24}$$

$$q_1 = -\frac{(c - a + n\,t)(m + b\,m + 1)}{(b + 1)(-m\,b^2 + 2\,m + 2)} \tag{25}$$

$$q_2 = -\frac{(b + 2)(c - a + n\,t)}{(b + 1)(-m\,b^2 + 2\,m + 2)} \tag{26}$$

$$a_1 = a_2 = t \tag{27}$$

Thus, privatizing port 2 will increase both ports' service prices, $\frac{\partial p_1}{\partial m} > 0$ *and* $\frac{\partial p_2}{\partial m} > 0$. The privatization of port 2 will also increase the service quantity of port 1, but reduce the service quantity of port 2, $\frac{\partial q_1}{\partial m} > 0$ *and* $\frac{\partial q_2}{\partial m} < 0$ and the overall service quantity: $\frac{\partial(q_1+q_2)}{\partial m} < 0$. These findings are consistent with the Cournot competition scenario.

When we substitute (23) - (27) into (9), the social welfare W can be obtained based on the function $W(b,m,n,t)^{pp}$ (see appendix for full formulation). The government will choose an optimal emission control tax t: $\frac{\partial W(b,m,n,t)^{pp}}{\partial t} = 0$ to maximize social welfare, so the optimal t is obtained through:

$$t = \frac{\eta}{\theta} \tag{28}$$

where

$$\begin{aligned} \eta = (a - c)(&24\,b + 24\,m + 2\,n + 36\,b\,m - 2\,b\,n - 8\,m\,n + 12\,b\,m^2 + 3\,b^2 m - 12\,b^3 m - 3\,b^4 m \\ &- 2\,m^2 n + 6\,b^2 + 6\,m^2 + 3\,b^2 m^2 - 6\,b^3 m^2 - 3\,b^4 m^2 + 4\,b^3 m^2 n + 2\,b^4 m^2 n \\ &- 10\,b\,m\,n - 4\,b\,m^2 n + 6\,b^2 m\,n + 10\,b^3 m\,n + 2\,b^4 m\,n + 18) \end{aligned}$$

$$\begin{aligned} \theta = 2\,(&- b^6 m^2 n + 4\,b^6 m^2 - 2\,b^5 m^2 n + 8\,b^5 m^2 + b^4 m^2 n^2 - 12\,b^4 m^2 + b^4 m\,n^2 + b^4 m\,n - 16\,b^4 m \\ &+ 2\,b^3 m^2 n^2 + 2\,b^3 m^2 n - 32\,b^3 m^2 + 5\,b^3 m\,n^2 - 4\,b^3 m\,n - 32\,b^3 m + 3\,b^2 m^2 n \\ &+ 3\,b^2 m\,n^2 - b^2 m\,n + 16\,b^2 m + 2\,b^2 n + 16\,b^2 - 2\,b\,m^2 n^2 + 4\,b\,m^2 n + 32\,b\,m^2 \\ &- 5\,b\,m\,n^2 + 20\,b\,m\,n + 64\,b\,m - b\,n^2 + 16\,b\,n + 32\,b - m^2 n^2 + 2\,m^2 n + 16\,m^2 \\ &- 4\,m\,n^2 + 16\,m\,n + 32\,m + n^2 + 14\,n + 16) \end{aligned}$$

Privatizing Port 2 will reduce the optimal emission tax: $\frac{\partial t}{\partial m} < 0$, similar to the Cournot competition scenario.

Substitution of (28) into (25) - (27) to update q₁, q₂, a₁, a₂, and substitution of the updated q₁, q₂, a₁, a₂ into (5) gives the re-written Environment damage (ED):

$$ED = \frac{\iota}{\kappa} \tag{29}$$

where

$$\begin{aligned}\iota = (a - c)^2(&16\,b + 16\,m + 11\,n + 24\,b\,m + 6\,b\,n + 18\,m\,n + 8\,b\,m^2 + 2\,b^2m - 8\,b^3m - 2\,b^4m \\ &- b^2n + 3\,m^2n + 4\,b^2 + 4\,m^2 + 2\,b^2m^2 - 4\,b^3m^2 - 2\,b^4m^2 + b^2m^2n - 4\,b^3m^2n \\ &- 2\,b^4m^2n + 20\,b\,m\,n + 6\,b\,m^2n - 8\,b^2m\,n - 12\,b^3m\,n - 2\,b^4m\,n + 12)^2\end{aligned}$$

$$\begin{aligned}\kappa = 8\,(&- b^6m^2n + 4\,b^6m^2 - 2\,b^5m^2n + 8\,b^5m^2 + b^4m^2n^2 - 12\,b^4m^2 + b^4m\,n^2 + b^4m\,n - 16\,b^4m \\ &+ 2\,b^3m^2n^2 + 2\,b^3m^2n - 32\,b^3m^2 + 5\,b^3m\,n^2 - 4\,b^3m\,n - 32\,b^3m + 3\,b^2m^2n \\ &+ 3\,b^2m\,n^2 - b^2m\,n + 16\,b^2m + 2\,b^2n + 16\,b^2 - 2\,b\,m^2n^2 + 4\,b\,m^2n + 32\,b\,m^2 \\ &- 5\,b\,m\,n^2 + 20\,b\,m\,n + 64\,b\,m - b\,n^2 + 16\,b\,n + 32\,b - m^2n^2 + 2\,m^2n + 16\,m^2 \\ &- 4\,m\,n^2 + 16\,m\,n + 32\,m + n^2 + 14\,n + 16)^2\end{aligned}$$

We find that $\frac{\partial ED}{\partial m}$ is not monotonous, implying that the effect of privatization on environmental damage is also U-shaped in Bertrand competition.

When we substitute (28) into (23) - (27) and then substitute the updated q₁, q₂, p₁, p₂, a₁, a₂ into (9) leads to a simplified social welfare W:

$$\mathrm{W} = \frac{\lambda}{\mu} \tag{30}$$

where

$$\begin{aligned}\lambda = (a - c)^2(&70\,b + 118\,m + 4\,n + 152\,b\,m - 4\,b\,n - 16\,m\,n + 50\,b\,m^2 - 30\,b^2m - 80\,b^3m \\ &- 16\,b^4m - 4\,m^2n + 9\,b^2 + 25\,m^2 + 9\,b^2m^2 - 32\,b^3m^2 - 16\,b^4m^2 + 8\,b^3m^2n \\ &+ 4\,b^4m^2n - 20\,b\,m\,n - 8\,b\,m^2n + 12\,b^2m\,n + 20\,b^3m\,n + 4\,b^4m\,n + 65)\end{aligned}$$

$$\begin{aligned}\mu = 4\,(&- b^6m^2n + 4\,b^6m^2 - 2\,b^5m^2n + 8\,b^5m^2 + b^4m^2n^2 - 12\,b^4m^2 + b^4m\,n^2 + b^4m\,n - 16\,b^4m \\ &+ 2\,b^3m^2n^2 + 2\,b^3m^2n - 32\,b^3m^2 + 5\,b^3m\,n^2 - 4\,b^3m\,n - 32\,b^3m + 3\,b^2m^2n \\ &+ 3\,b^2m\,n^2 - b^2m\,n + 16\,b^2m + 2\,b^2n + 16\,b^2 - 2\,b\,m^2n^2 + 4\,b\,m^2n + 32\,b\,m^2 \\ &- 5\,b\,m\,n^2 + 20\,b\,m\,n + 64\,b\,m - b\,n^2 + 16\,b\,n + 32\,b - m^2n^2 + 2\,m^2n + 16\,m^2 \\ &- 4\,m\,n^2 + 16\,m\,n + 32\,m + n^2 + 14\,n + 16)\end{aligned}$$

By maximizing the social welfare w (30): $\frac{\partial W}{\partial m} = 0$, we can get the optimal privatization level:

$$m = \frac{3\,b + 9\,n + 6\,b\,n - b^2n + 7\,b^2 - 6}{(b + 1)(9\,b - 7\,n - 3\,b\,n + 6\,b^2n + 2\,b^3n - 24\,b^2 - 8\,b^3 + 34)} \tag{31}$$

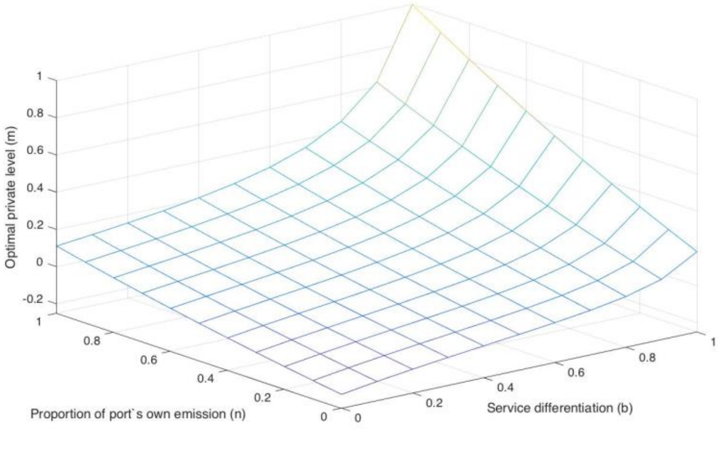

Figure 33 The optimal private level of port 2 in Bertrand competition

Source: Authors' own elaboration.

Unlike the combined effect of service differentiation (b) and proportion of port operations' emissions (n) on the optimal privatization level in Cournot competition, we found that $\frac{\partial m}{\partial b} > 0 \; and \; \frac{\partial m}{\partial n} > 0$, implying that an increase in service similarity or proportion of port operations' emissions will prefer further privatization of port 2.

Based on the optimal private level m (31), we can get the optimal tax:

$$t = \frac{(a-c)(3b - 5n - bn + 5b^2 n + b^3 n - 12b^2 - 3b^3 + 18)}{b^3 n^2 + 2b^3 n - 23b^3 + 5b^2 n^2 - 12b^2 n - 21b^2 - bn^2 - 2bn + 32b - 5n^2 + 20n + 28} \tag{32}$$

We can find that $\frac{\partial t}{\partial b}$ is not monotonous and U-shaped.

Given the optimal private level m (31) and the optimal tax t (32), we can obtain the optimal social welfare (W^{pp}), consumer surplus (CS^{pp}), environment damage (ED^{pp}), total emission tax^{pp}, profit of port 1 (R_1^{pp}), the revenue of port 2 (G^{pp}), q_1, q_2, and p_1, p_2. These can be found in the appendix.

5.3.3 Sub-game 3: Cooperation among the two ports

Consider a situation in which the two ports choose to cooperate strategically by jointly adjusting overall capacity (to influence cargo volume) or setting a unified price. In this case, the two ports can be considered as one entity aimed at maximizing their summed goals but still keeping their own profits in this strategic alliance.

The FOC for both ports can be written as:

$\frac{\partial(R_1+G)}{\partial q_1} = \frac{\partial(R_1+G)}{\partial q_2} = 0$ **or** $\frac{\partial(R_1+G)}{\partial p_1} = \frac{\partial(R_1+G)}{\partial p_2} = 0$, **and** $\frac{\partial(R_1+G)}{\partial a_1} = \frac{\partial(R_1+G)}{\partial a_2} = 0$, we can get the result:

$$q_1 = q_2 = -\frac{c - a + nt}{(b+1)(m+1)} \tag{33}$$

$$p_1 = p_2 = \frac{c + am + nt}{m+1} \tag{34}$$

$$a_1 = a_2 = t \tag{35}$$

Substitution of (33) – (35) into (9) gives the function for *W(b,m,n,t)^{coop}* (see appendix). The government will maximize $W(b,m,n,t)^{coop}$ by choosing the optimal emission tax: $\frac{\partial W(b.m,n.t)^{coop}}{\partial t}$=0. The optimal emission tax is:

$t(b,m,n)^{\,coop}$*(See appendix for full calculation)* *(36)*

We found that $\frac{\partial t(b,m,n)^{\,coop}}{\partial m} < 0$, implying that the privatization of Port 2 will reduce the optimal emission tax, which is consistent with the other sub-games.

Substitute (36) into (33), (34) to update q_1, q_2, a_1, a_2, then substitute the updated q_1, q_2, a_1, a_2 into (5), the re-written Environment damage becomes:

$ED(b,m,n)^{coop}$ *(See appendix)* *(37)*

Note that $\frac{\partial ED(b,m,n)^{coop}}{\partial m} < 0$, suggesting that privatization of Port 2 will reduce the environmental damage, which is not consistent with the two inter-port competition scenarios.

Substitute (36) into (33) - (35) to update them, then substitute the updated q_1, q_2, p_1, p_2, a_1, a_2 into (9), we get the social welfare W:

$W(b,m,n)^{coop}$ *(See appendix)* *(38)*

By maximizing the social welfare w (38): $\frac{\partial W(b,m,n)^{coop}}{\partial m} = 0$, we can get the optimal privatization level:

$$m = \frac{n-1}{4b - n - bn + 4} \tag{39}$$

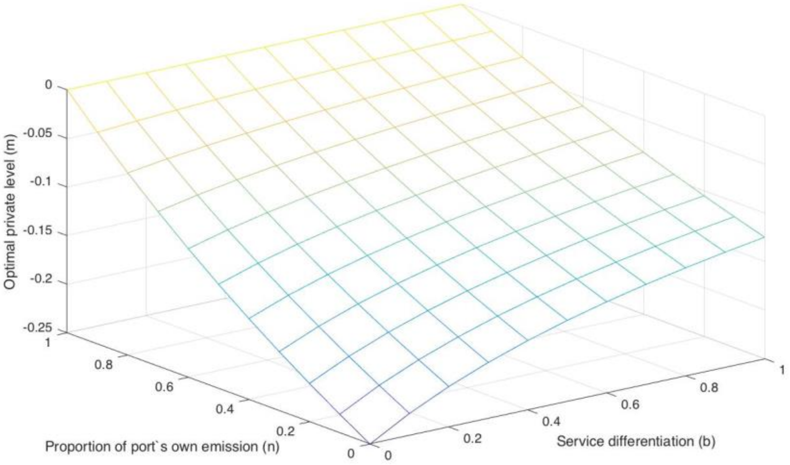

Figure 34 The optimal private level of port 2 in cooperation

Source: Authors' own elaboration.

Note that $m \in (-0.25,0)$, implying that the optimal private level in the cooperation sub game is highly public concerned. $\frac{\partial m}{\partial n} > 0$ *and* $\frac{\partial m}{\partial b} > 0$ indicates that a higher proportion of port operations' emissions and a higher service similarity will support a relatively high private level of port 2, which is still highly public concerned.

Substitute (39) into (36), the optimal emission tax becomes:

$$t = -\frac{(a-c)(n-3)}{4b + 3n - bn - n^2 + 3} \tag{40}$$

where $\frac{\partial t^{coop}}{\partial b} < 0$, implying that an increase in service similarity will reduce the optimal emission control tax, which is different from the previous sub-games.

All the functions for W^{coop}, CS^{coop}, ED^{coop}, total emission tax^{coop}, R_1^{coop}, G^{coop}, q_1^{coop}/q_2^{coop} and p_1^{coop}/p_2^{coop} can be found in the appendix.

5.4 A comparison of the results of the three sub-games

In this section, we compare the private level (m), optimal emission control tax (t), and other equilibrium statuses under Cournot and Bertrand competition and cooperation.

5.4.1 Optimal private level of port 2 (m)

We found that the optimal private level (m) of port 2 under Cournot and Bertrand competitions varies between fully private and highly public concerned, while under the cooperation scenario, the government will prefer a highly public concerned port 2 or close to highly public concerned port 2 to maximize social welfare (see Figure 22, 23, and 24).

5.4.2 *Optimal emission control tax (t)*

After removing the common constant part $(a - c)$, we found that the optimal emission control tax is always higher in Bertrand competition than in Cournot competition: $t^{pp} > t^{qq}$, $b \in (0,1)$, and unless the ports' services are highly substitutable, the optimal emission tax is always highest in the cooperation sub-game: $t^{coop} > t^{pp} > t^{qq}$.

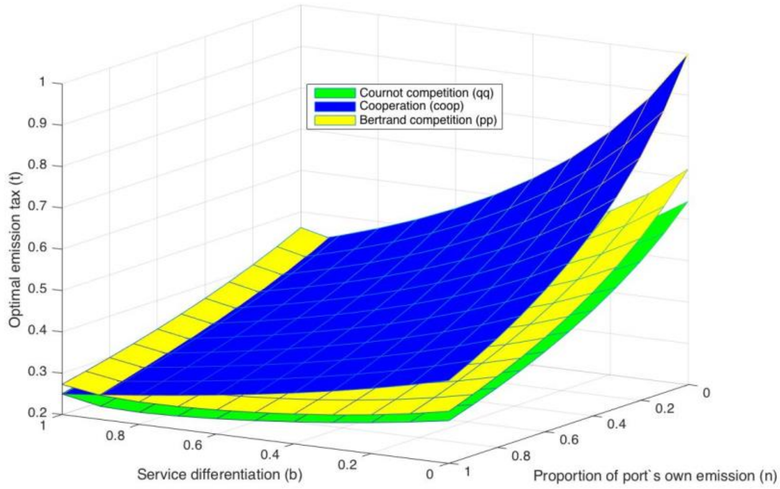

Figure 35 The optimal emission tax in inter-port competition and cooperation scenarios

Source: Authors' own elaboration.

Since we have mentioned that the optimal emission control tax represents the government`s desire/requirement to protect the environment against pollution, the sequence suggests that the government needs to set the highest effort/requirements in the cooperation scenario (monopolistic with a high level of nationalization), especially if the services of the ports are highly differentiated, compared to the relatively lower efforts in the competition scenarios.

5.4.3 *Environment damage (ED)*

After removing the constant part $(a - c)^2$, we found that Bertrand competition always yields a higher ED than Cournot competition: $ED^{pp} > ED^{qq}$, $b \in (0,1)$. Moreover, the cooperation sub game will produce a lot more ED than the inter-competition sub-games if the port services are less substitutable and with a lower share of the emissions linked to port operations.

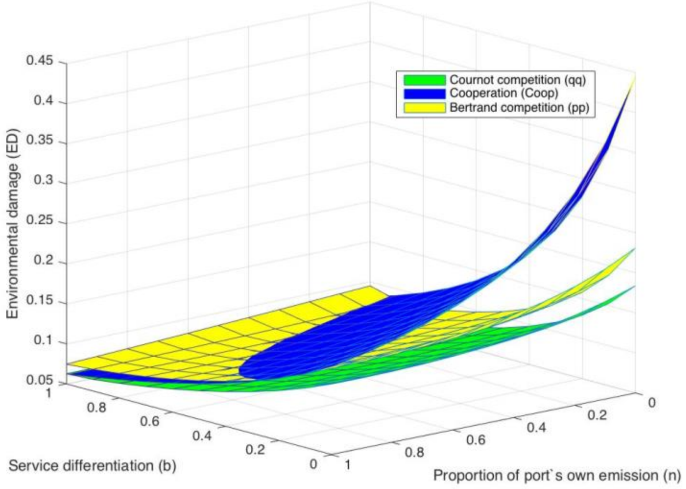

Figure 36 The Environmental damage in inter-port competition and cooperation scenarios

Source: Authors' own elaboration.

The relationship between private level and environmental damage can be solved by converting the optimal port privatization level (m): $m = f(b)$ into its inverse form $b = f`(m)$, then substitute this inverse function into the function of ED to check the relationship.

Assume n=0.2, and after removing the common constant part $(a - c)^2$, then the relationship between ED and m in the three scenarios is depicted in ***Figure 37***.

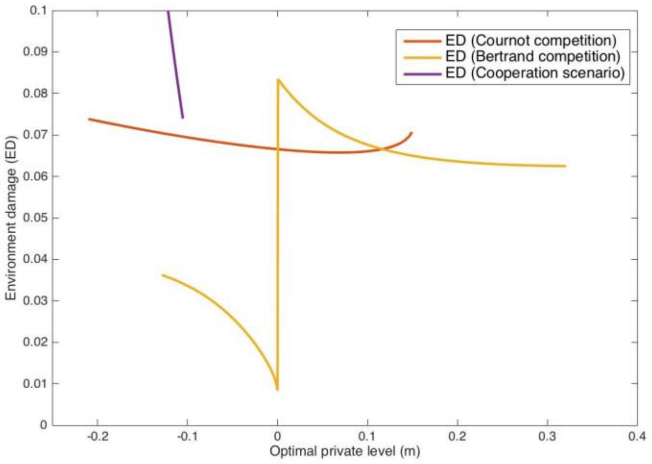

Figure 37 The relationship between environmental damage (ED) and the optimal private level of port 2 (m) under inter-port competitions and cooperation scenarios (assuming n=0.2)

Source: Author`s own elaboration.

This numeric example is consistent with the previous findings that the private level of port 2 (m) has a non-monotonous effect on ED in the inter-port competition scenarios and a monotonous decreasing effect on ED in the cooperation scenario. Note that when n=0.2, the optimal private level in all three scenarios varies between: $m^{Cournot} \in (-0.2105, 0.1494)$, $m^{Bertrand} \in (-0.1288, 0.3208), and\ m^{coop} \in (-0.2105, -0.1053)$.

5.4.4 Ratio (emission tax revenue/ED and emission tax/marginal ED)

The ratio emission tax revenue/ED indicates how much the total tax revenue compensates the environmental damage: $ratio\ \left(\frac{emission\ tax\ revenue}{ED}\right) = \frac{total\ emission\ tax\ revenue}{ED} = \frac{t*(e_1+e_2)}{ED} = \frac{2*t}{e_1+e_2}$

$$Ratio^{qq}\left(\frac{ETR}{ED}\right) = \frac{15\,b + 5\,n - 4\,b\,n - 18}{2\,(5\,b - 2\,n + 2\,b\,n - 6)}$$
$$Ratio^{pp}\left(\frac{ETR}{ED}\right) = \frac{3\,b - 5\,n - b\,n + 5\,b^2n + b^3n - 12\,b^2 - 3\,b^3 + 18}{2\,(b + 2\,n - b^2n - 4\,b^2 - b^3 + 6)}$$
$$Ratio^{coop}\left(\frac{ETR}{ED}\right) = \frac{3-n}{2} \in (1{,}1.5), n \in (0{,}1)$$

We found that $Ratio^{coop}\left(\frac{ETR}{ED}\right)$ $is\ always\ bigger\ than\ Ratio^{qq}\left(\frac{ETR}{ED}\right)$ $and\ Ratio^{pp}\left(\frac{ETR}{ED}\right)$, where $Ratio^{coop}\left(\frac{ETR}{ED}\right) \in (1{,}1.5)$ and $Ratio^{qq}\left(\frac{ETR}{ED}\right), Ratio^{pp}\left(\frac{ETR}{ED}\right) \in (0.812, 1.5)$. This suggests that in the cooperation sub-game, ports are always paying more tax than the ED they caused, while in Cournot and Bertrand competition, ports may pay an emission tax that is higher or lower than the ED they caused, depending on the combination of (b) and (n). Furthermore, $\frac{\partial ratio\ (\frac{ETR}{ED})}{\partial n} < 0$ and $\frac{\partial ratio\ (\frac{ETR}{ED})}{\partial b} > 0$ holds in all scenarios, implying that the increasing share of port operations' emissions will lead the port to pay fewer taxes compared to the ED it caused, and the ports will tend to pay more taxes to compensate for their ED if they offer a more similar service.

Based on the ED in the different scenarios, we can obtain the marginal ED:

$$MED^{qq} = -\frac{(8\,a - 8\,c)(5\,b - 2\,n + 2\,b\,n - 6)}{4\,b^2n - 25\,b^2 + 4\,b\,n^2 - 22\,b\,n + 4\,b - 5\,n^2 + 20\,n + 28}$$
$$MED^{pp} = \frac{(8\,a - 8\,c)(b + 2\,n - b^2n - 4\,b^2 - b^3 + 6)}{b^3n^2 + 2\,b^3n - 23\,b^3 + 5\,b^2n^2 - 12\,b^2n - 21\,b^2 - b\,n^2 - 2\,b\,n + 32\,b - 5\,n^2 + 20\,n + 28}$$
$$MED^{coop} = \frac{8\,a - 8\,c}{4\,b + 3\,n - b\,n - n^2 + 3}$$

So, the ratios between emission tax and marginal ED are:

$$Ratio^{qq}\left(\frac{t}{MED}\right) = \frac{15\,b + 5\,n - 4\,b\,n - 18}{40\,b - 16\,n + 16\,b\,n - 48}$$
$$Ratio^{pp}\left(\frac{t}{MED}\right) = \frac{3\,b - 5\,n - b\,n + 5\,b^2n + b^3n - 12\,b^2 - 3\,b^3 + 18}{8\,(b + 2\,n - b^2n - 4\,b^2 - b^3 + 6)}$$
$$Ratio^{coop}\left(\frac{t}{MED}\right) = \frac{3-n}{8}$$

We found that $Ratio^{pp}\left(\frac{t}{MED}\right) < Ratio^{coop}\left(\frac{t}{MED}\right) < 1\ and\ Ratio^{qq}\left(\frac{t}{MED}\right) < Ratio^{coop}\left(\frac{t}{MED}\right) < 1, b, n \in (0{,}1)$, showing that the optimal emission tax is always lower than the marginal ED in all scenarios. In the cooperation sub game, ports have the highest MED compensation ratio.

5.4.5 Social welfare (W)

After removing the common constant part $(a-c)^2$, we found that the Social welfare^{pp} is always higher than Social welfare^{qq}, except if the ports' services are highly substitutable. Social welfare^{coop} is significantly higher than in the other inter-competition sub-games. An increase in the service similarity and the share of port operations' emissions will always compromise social welfare: $\frac{\partial w}{\partial b} < 0\ and\ \frac{\partial w}{\partial n} < 0.$

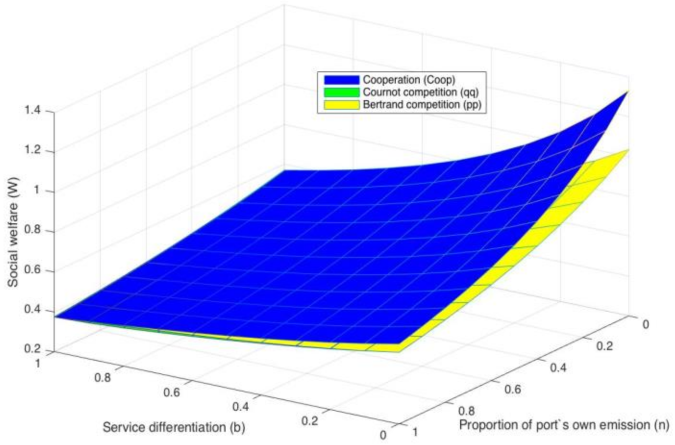

Figure 38 The social welfare under inter-port competition and cooperation scenarios

Source: Authors' own elaboration

5.4.6 *Profit of port 1 (R_1) and payoff of port 2 (G)*

The common constant part $(a-c)^2$ are removed in both R$_1$, profit 2, and G.

We found that R_1^{pp} is slightly higher than R_1^{qq} except when the port services are highly substitutable. However, R_1^{coop} is always much lower than in the other sub-games, indicating that private Port 1 will always suffer a loss in the cooperation sub games, compared to the other scenarios.

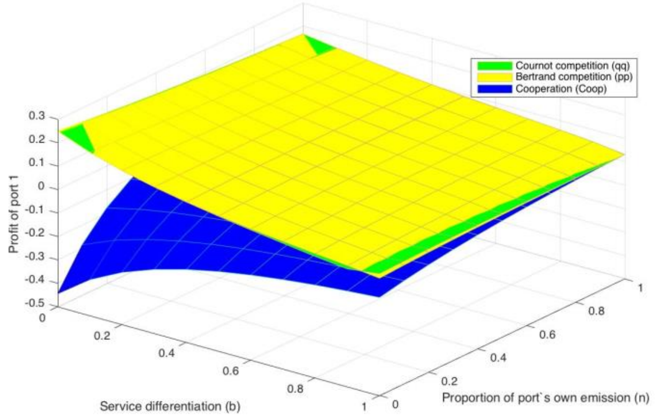

Figure 39 The profit of port 1 under inter-port competition and cooperation scenarios

Source: Authors' own elaboration

The profit of Port 2 in the cooperation scenario is always much lower than in the other games. Cournot competition mostly yields a positive result.

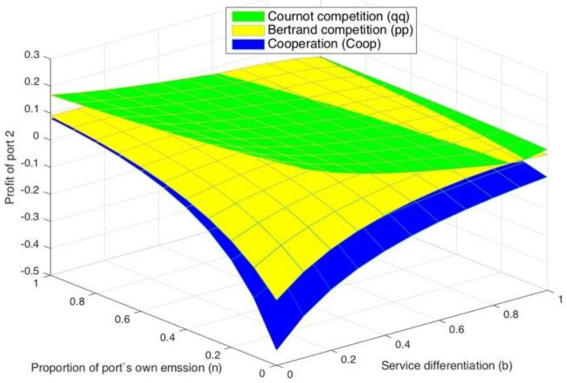

Figure 40 The profit of port 2 under inter-port competition and cooperation

Source: Authors' own elaboration

The relation of the payoff of Port 2 (G) in the inter-port competition sub-games varies depending on the combination of (b) and (n). The cooperation scenario always brings extra benefits to the partial public port 2: $G^{coop} > G^{qq}\ and\ G^{coop} > G^{pp}, b, n \in (0,1)$, although port 2's profit is much lower under cooperation than under inter-port competition. This finding suggests that port 2 has to sacrifice its profit for more consumer surplus during the transfer from competition to cooperation.

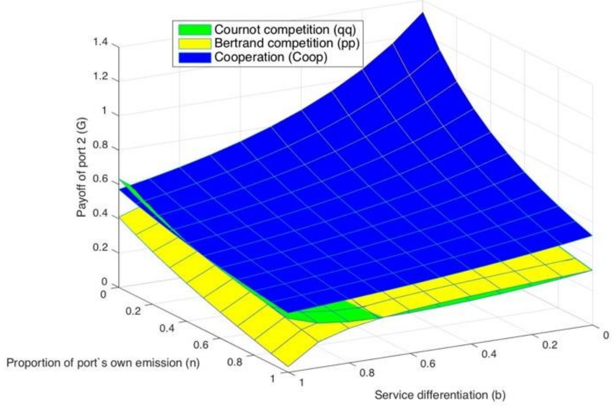

Figure 41 The payoff of port 2 in the inter-port competition and cooperation scenarios

Source: Authors' own elaboration

All the extreme points in profit of Port 1 and 2 and payoff of Port 2 are greatly linked to the port privatization status. When port 2 is heavily nationalized, the profits of both ports will suffer from the overcapacity with profit loss (especially for the single objective profit-driven port 1). Since Port 2 has a combined objective (profit with CS), Port 2 will face a tradeoff between profit and CS, and it may end up with a positive overall result. Based on the calculation, private Port 1 will not be willing to cooperate with the partial public Port 2 since cooperation will negatively affect its profitability. In contrast, partial public Port 2 will tend to opt for cooperation with private Port 1 due to the additional benefits brought by such a strategic port alliance.

5.4.7 Quantity

We found that for port 1 $q_1^{coop} > q_1^{pp} > q_1^{qq}, b, n \in (0,1)$ holds, for port 2, $q_2^{qq} > q_2^{pp}, b, n \in (0,1)$ holds, and for the whole capacity/cargo volume, $q_1^{qq} + q_2^{qq} < q_1^{pp} + q_2^{pp} < q_1^{coop} + q_2^{coop}$. Furthermore, $\frac{\partial q_1^{coop}}{\partial n} = \frac{\partial q_2^{coop}}{\partial n} < 0, \frac{\partial q_2^{qq}}{\partial n} < 0, \frac{\partial q_2^{pp}}{\partial n} < 0$, but $\frac{\partial q_1^{qq}}{\partial n}$ and $\frac{\partial q_1^{pp}}{\partial n}$ is non-monotonous in terms of n.

5.5 Application in the scenario of Shenzhen Port and Hongkong Port

(This background part is identical to the 3.5) Applying the model to real-world cases presents a formidable challenge to faithfully replicate the theoretical game setting in practical scenarios. To provide a supplementary illustration, we have included an example that explores the dynamics of port competition between Hong Kong and Shenzhen. It is worth noting that while this case offers valuable insights, it may not perfectly align with all the underlying assumptions of our theoretical game setting.

Shenzhen Port and Hongkong Port are spatially close with certain overlapping but not identical hinterland in the Pearl River delta (PRD).

Figure 42 Shenzhen Port and HongKong Port

Source: http://worldportsource.com

- Shenzhen Port

Shenzhen port consists of four major container terminal complexes, i.e., Yantian, Shekou and Chiwan/Mawan. The ownership structure of those 4 terminals can be found in the Table 12 (as in 2015). All the terminals are administrated by the Shenzhen harbor bureau (Port authority) and mainly “controlled” by it, since the shareholders of those terminals are mainly state-owned & municipal-owned (local) companies.

Table 16 Ownership structure of Shenzhen Port

	Yantian International Container Terminal	Shekou container terminals	Chiwan container terminal	Mawan container terminal
Shareholder information	19.8 bn state-own	CMHI: 80%	Chiwan Wharf Holdings Limited: 55%	CHMI: 70%

	Total 27.1 bn investment	**Modern terminal limited: 20% (subsidy of The Wharf (Holdings))***	**Kerry Logistics Network Limited:25%***	Chiwan Wharf Holdings Limited: 55%
			MTL chiwan: 20% (CHMI: 60%, **Modern terminal limited: 40%*)**	
Private level	26.94%	20%	33%	0%
Throughput, in million TEU	12.16	5.19	4.76	1.34
Aggregated private level	32.75% (between 0% and 100%)			

*: Bold means the private entities.
Source: Various sources

- Hong Kong Port

Hong Kong`s container terminals are situated in the Kwai Chung-Tsing Yi basin. There are nine terminals operated by five different operators, namely Modern Terminals Ltd (MTL) (subsidiary of The Wharf (Holdings)), Hongkong International Terminals Ltd (HIT), COSCO-Hong Kong International Terminals Ltd (COSCO-HIT), Goodman DP World and Asia Container Terminals Ltd (ACT). The HK government is the lessor of land sites to the private terminal operating companies, and terminals are administrated by the maritime department (port authority). Neither the HK government nor the maritime department owns or operates container terminal facilities (Dong et al., 2002). All operators are private and profit-driven (although Cosco Port is state-owned, here we consider it as an investment company and profit-driven). Thus**, we consider the Port of Hongkong as a private (profit-driven) port, although it is under landlord mode.**

Table 17 Ownership structure of Hongkong Port

Abb. name of port operator	**Full name**	**Shareholders**	**Terminal No.**
MTL	Modern terminal Ltd	Subsidy of The Wharf (Holdings)	1, 2, 5, 9 South
DPI	Dubai Port International Terminals Ltd.	DP World	3
HIT	HONGKONG international terminals Ltd	HPH 66.5%, Portcapital Ltd 20%, China resource 10%	4, 6, 7, 8*, 9 North
COSCO	Cosco Pacific Ltd.	COSCO SHIPPING Ports Ltd.	8*
ACT	Asia Container Terminals Ltd		8 West

*: it means No. 8 terminal East is a joint-adventure between Cosco port and HIT
Source: Various sources

- Cost structure

In regard to the cost structure, it’s important to acknowledge that specific cost data is unavailable. Furthermore, we have made an assumption that both ports employ similar technology. Therefore, in the case of Shenzhen and Hong Kong, we assume that the average cost per TEU (Twenty-Foot Equivalent Unit) for both ports is equivalent (c).

- Throughput (q) and service price (p)

We collected the two ports` throughput and service price (terminal handling charge) data as of 2015.
The throughput for SZ port is $q_1 = 23.45$ million TEU
The throughput for HK port is $q_2 = 20.07$ million TEU.

We assume that the terminal handling charge is an approximate index for the port service price. We collected the 20` dry container THC from the OOCL website: the average THC at HK for an inbound container is 2,019 HKD/TEU, and for an outbound container is 2,101 HKD/TEU. The average THC at Shenzhen for inbound containers is 919 RMB/TEU and 886 RMB/TEU for outbound containers.
The average THC in HK is $p_2 = 1{,}813$ RMB/TEU (using the exchange rate between HKD and RMB)
The average THC in SZ is $p_1 = 903$ RMB/TEU.

- Results

In the scenario where the Port of Shenzhen and the Port of Hong Kong align with all the underlying assumptions, we can derive the following results: The service differentiation parameter b can be determined as b=0.73. The parameter a, representing the intercept of the demand curve, can be calculated as a=39,007.

Table 18 Optimal private level in SZ-HK case (as in n=1 or n=0):

	n=1	n=0
m^{qq}	0.338	0.102
m^{pp}	0.38	-0.00163
m^{coop}	0	-0.144

The aggregated private level of Shenzhen port is 32.75%, which can be converted as 0.16 in the linear scale of (-0.25,1). Assuming that currently, the Port of Hongkong and the Port of Shenzhen are competing in price, the current private level falls in the range of optimal private level (-0.00163, 0.38), where the exact number depends on the proportion of the port`s own emission (n).

Table 19 Optimal emission tax, MED after removing the constant common part (a-c):

	n=1	n=0
Emission tax (Cournot)	0.230	0.401
Emission tax (Bertrand)	0.240	0.404
Emission tax (Cooperation)	0.278	0.506
MED (Cournot)	1.071	1.068
MED (Bertrand)	1.095	1.078
MED (Cooperation)	1.112	1.351

It suggests that marginal environmental damage (MED) is always higher than optimal emission tax in all three scenarios.

5.6 Conclusions

With the increasing concern about environmental issues in port areas, the government or any other relevant public body might decide to charge a tax on emissions in port areas. These emissions can be ship-related or linked to port operations. In this paper, we modeled emission taxes in combination with the privatization level of the port in view of assessing their interplay in different port competition and cooperation settings and considering different levels of service similarity between ports and the share of port operations in total emissions. Building further upon the models presented by Xu et al. (2016), we compared three equilibriums as a function of the service differentiation level (b) and proportion of the port`s own emission (n) in Cournot competition, Bertrand competition, and cooperation sub-games. A numeric example is present in the context of Shenzhen Port and Hongkong Port. The results point to a range of relevant implications for port managers and policymakers.

First, we found that the optimal private level of a partial public port under Cournot and Bertrand competition varies between a fully private and a highly public concerned port, while under the cooperation scenario, the government will prefer a highly public concerned port or close to highly public concerned port to maximize overall social welfare.

Second, in terms of the optimal emission tax, the governments will need to make more and stricter efforts to enhance environmental protection in a port cooperation (monopolistic) situation than in the case of inter-port competition. The optimal emission tax is always lower than the marginal environmental damage (MED) in the three scenarios. Ports achieve the highest MED compensation ratio in the cooperation sub game.

Third, ports always yield a higher ED in Bertrand competition than in Cournot competition (since the optimal quantity is lower in Cournot competition). However, ports will generate the highest ED in the cooperation scenario, especially if their services are less substitutable and when port operations are only responsible for a small share of total port emissions. In the cooperation scenario, (monopolistic) ports will have to pay more tax than the environmental damage they cause, which is not the case in the Cournot and Bertrand competition sub-games.

Fourth, the privatization of port 2 has a non-monotonous effect on the ED in the inter-port competition scenarios. This is due to two phenomena. First, privatization reduces the cargo volume/capacity so that it directly reduces the emissions. Second, privatization also reduces the optimal emission tax so that the pollution abatement/reduction measures will also be reduced. In the cooperation scenario, the privatization of Port 2 has a monotonous decreasing effect on the ED.

Fifth, in the cooperation sub game, ports will generate higher social welfare than in the Cournot and Bertrand competition scenarios, which also matches the willingness to cooperate of the partial public port 2 (port 2 will be better off if it chooses to cooperate). However, private port 1 has no incentive to cooperate, given the negative impact of cooperation on its profit. So, unless the partial public port 2 or the government can (partially) compensate the profit losses of private port 1 when opting for a strategic alliance, private port 1 will not be willing to join the port alliance. In other words, the public side may need to subsidize/support the ports to promote cooperation. These outcomes demonstrate that ports may have conflicting interests when it comes to cooperation schemes. Some forms of compensation might need to be provided in order to incentivize ports to follow a path toward cooperation.

Sixth, the government may have conflicting opinions on port cooperation regarding environmental protection, the maximization of social welfare, and the satisfaction of individual motivations. Again, in terms of social welfare, port cooperation yields the best results, but it produces the highest ED, with negative effects on both ports` profitability. In this case, the government will have to make a choice between subsidizing/supporting both ports to promote cooperation, to gain more capacity (CS) with a higher ED, or to keep both ports in a competition status with higher profit but lower capacity (CS) and lower ED.

Next to giving insights to public policymakers, the findings are also relevant to port users. Charging an emission tax will typically lead to a reduction in the port’s cargo volume (due to the associated cost increase), which will damage the profitability of both port operators and shipping lines. When the government sets a higher private level, it will tend to raise the service price (with lower capacity) and make the optimal emission tax lower, which actually helps to increase their profitability. In contrast, charging an emission control tax and privatizing the port will always increase the shipper`s cost. Given the rising environmental concerns and growing awareness of the importance of stakeholder relations management, the internalization of external costs is inevitable.

The results imply that government decisions regarding port ownership reform and emission tax policies can serve as strategic tools to simultaneously enhance social welfare, environmental protection, and profitability in the port industry. This provides a fresh perspective for policymakers in the field of ports and transportation infrastructure. Furthermore, these findings offer valuable insights to port authorities and container terminal operators, assisting them in policy-making and strategic decision formulation. For example, to balance environmental protection and social welfare, the government may need to carefully assess the level of port emission tax and the degree of port privatization combined. Increasing emission taxes can be a means to prioritize environmental protection, while adjusting the levels of port privatization may be more conducive to improving social welfare.

The author is well known that this study is a theoretical study into the emission tax, partial privatization of port, and competition/cooperation of port, which may deviate from reality and lack practicality. The proposed modeling exercise comes with some simplifications and limitations. The choice of the inverse demand function, the cost function, the consumer surplus function, etc., may affect the final outcomes. Also, in real life, it might be convenient to impose a uniform emission tax for all domestic ports. When it comes to international ports, however, there are many tensions between different nations regarding the fairness of emission taxes, and this may result in not reaching a level playing field in port competition, leading to unnatural cargo shifts between ports. Furthermore, it is also interesting to investigate how the optimal private level and emission tax will be affected by a third market (transit market).

Appendix

➢ The inter median result in sub-game analysis:

- Cournot competition

$$
\begin{aligned}
W(b,m,n,t)^{qq} = {} & n\,t\Bigl(t + \frac{(m-b+1)(c-a+n\,t)}{-m\,b^2+2\,m+2}\Bigr) - t\Bigl(2\,t - \frac{(b\,m-2)(c-a+n\,t)}{-m\,b^2+2\,m+2} + \\
& \frac{(m-b+1)(c-a+n\,t)}{-m\,b^2+2\,m+2}\Bigr) - n\,t^2 - \frac{\Bigl(2\,t - \frac{(b\,m-2)(c-a+n\,t)}{-m\,b^2+2\,m+2} + \frac{(m-b+1)(c-a+n\,t)}{-m\,b^2+2\,m+2}\Bigr)^2}{2} + n\,t\Bigl(t - \\
& \frac{(b\,m-2)(c-a+n\,t)}{-m\,b^2+2\,m+2}\Bigr) - \frac{c\,(b\,m-2)(c-a+n\,t)}{-m\,b^2+2\,m+2} + \frac{c\,(m-b+1)(c-a+n\,t)}{-m\,b^2+2\,m+2} + \\
& \frac{(b\,m-2)(c-a+n\,t)\bigl(2\,c-a\,b+b\,c+2\,a\,m+2\,n\,t+a\,b^2-b^2c-b^2n\,t+b\,n\,t-a\,b^2m\bigr)}{(-m\,b^2+2\,m+2)^2} + \\
& \frac{(b+1)(c-a+n\,t)^2\bigl(2\,b^2m-b\,m^2-4\,b\,m-3\,b+m^2+2\,m+5\bigr)}{2\,(-m\,b^2+2\,m+2)^2} - \\
& \frac{(m-b+1)\Bigl(a+\frac{(m-b+1)(c-a+n\,t)}{-m\,b^2+2\,m+2} - \frac{b\,(b\,m-2)(c-a+n\,t)}{-m\,b^2+2\,m+2}\Bigr)(c-a+n\,t)}{-m\,b^2+2\,m+2}
\end{aligned}
$$

- Bertrand competition

$$
\begin{aligned}
W(b,m,n,t)^{pp} = {} & -(a^2b^4m^2 + a^2b^4m + 2\,a^2b^3m^2 + 5\,a^2b^3m + 3\,a^2b^2m - 2\,a^2b\,m^2 - \\
& 5\,a^2b\,m - a^2b - a^2m^2 - 4\,a^2m + a^2 - 2\,a\,b^4c\,m^2 - 2\,a\,b^4c\,m - 2\,a\,b^4m^2n\,t + 3\,a\,b^4m^2t - 2\,a\,b^4m\,n\,t + \\
& 3\,a\,b^4m\,t - 4\,a\,b^3c\,m^2 - 10\,a\,b^3c\,m - 4\,a\,b^3m^2n\,t + 6\,a\,b^3m^2t - 10\,a\,b^3m\,n\,t + \\
& 12\,a\,b^3m\,t - 6\,a\,b^2c\,m - 3\,a\,b^2m^2t - 6\,a\,b^2m\,n\,t - 3\,a\,b^2m\,t - 6\,a\,b^2t + 4\,a\,b\,c\,m^2 + 10\,a\,b\,c\,m + 2\,a\,b\,c + \\
& 4\,a\,b\,m^2n\,t - 12\,a\,b\,m^2t + 10\,a\,b\,m\,n\,t - 36\,a\,b\,m\,t + 2\,a\,b\,n\,t - 24\,a\,b\,t + 2\,a\,c\,m^2 + 8\,a\,c\,m - 2\,a\,c + \\
& 2\,a\,m^2n\,t - 6\,a\,m^2t + 8\,a\,m\,n\,t - 24\,a\,m\,t - 2\,a\,n\,t - 18\,a\,t - b^6m^2n\,t^2 + 4\,b^6m^2t^2 - 2\,b^5m^2n\,t^2 + \\
& 8\,b^5m^2t^2 + b^4c^2m^2 + b^4c^2m + 2\,b^4c\,m^2n\,t - 3\,b^4c\,m^2t + 2\,b^4c\,m\,n\,t - 3\,b^4c\,m\,t + b^4m^2n^2t^2 - \\
& 12\,b^4m^2t^2 + b^4m\,n^2t^2 + b^4m\,n\,t^2 - 16\,b^4m\,t^2 + 2\,b^3c^2m^2 + 5\,b^3c^2m + 4\,b^3c\,m^2n\,t - 6\,b^3c\,m^2t + \\
& 10\,b^3c\,m\,n\,t - 12\,b^3c\,m\,t + 2\,b^3m^2n^2t^2 + 2\,b^3m^2n\,t^2 - 32\,b^3m^2t^2 + 5\,b^3m\,n^2t^2 - 4\,b^3m\,n\,t^2 - \\
& 32\,b^3m\,t^2 + 3\,b^2c^2m + 3\,b^2c\,m^2t + 6\,b^2c\,m\,n\,t + 3\,b^2c\,m\,t + 6\,b^2c\,t + 3\,b^2m^2n\,t^2 + 3\,b^2m\,n^2t^2 - \\
& b^2m\,n\,t^2 + 16\,b^2m\,t^2 + 2\,b^2n\,t^2 + 16\,b^2t^2 - 2\,b\,c^2m^2 - 5\,b\,c^2m - b\,c^2 - 4\,b\,c\,m^2n\,t + \\
& 12\,b\,c\,m^2t - 10\,b\,c\,m\,n\,t + 36\,b\,c\,m\,t - 2\,b\,c\,n\,t + 24\,b\,c\,t - 2\,b\,m^2n^2t^2 + 4\,b\,m^2n\,t^2 + 32\,b\,m^2t^2 - \\
& 5\,b\,m\,n^2t^2 + 20\,b\,m\,n\,t^2 + 64\,b\,m\,t^2 - b\,n^2t^2 + 16\,b\,n\,t^2 + 32\,b\,t^2 - c^2m^2 - 4\,c^2m + c^2 - 2\,c\,m^2n\,t + \\
& 6\,c\,m^2t - 8\,c\,m\,n\,t + 24\,c\,m\,t + 2\,c\,n\,t + 18\,c\,t - m^2n^2t^2 + 2\,m^2n\,t^2 + 16\,m^2t^2 - 4\,m\,n^2t^2 + 16\,m\,n\,t^2 + \\
& 32\,m\,t^2 + n^2t^2 + 14\,n\,t^2 + 16\,t^2)/((b + 1)^2(2\,m - b^2m + 2)^2)
\end{aligned}
$$

- Cooperation

$$
\begin{aligned}
W(b,m,n,t)^{coop} = {} & -(-2\,a^2b\,m - a^2b - 2\,a^2m + a^2 + 4\,a\,b\,c\,m + 2\,a\,b\,c + 4\,a\,b\,m\,n\,t - 6\,a\,b\,m\,t + \\
& 2\,a\,b\,n\,t - 6\,a\,b\,t + 4\,a\,c\,m - 2\,a\,c + 4\,a\,m\,n\,t - 6\,a\,m\,t - 2\,a\,n\,t - 6\,a\,t - b^2m^2n\,t^2 + 4\,b^2m^2t^2 - \\
& 2\,b^2m\,n\,t^2 + 8\,b^2m\,t^2 - b^2n\,t^2 + 4\,b^2t^2 - 2\,b\,c^2m - b\,c^2 - 4\,b\,c\,m\,n\,t + 6\,b\,c\,m\,t - 2\,b\,c\,n\,t + \\
& 6\,b\,c\,t - 2\,b\,m^2n\,t^2 + 8\,b\,m^2t^2 - 2\,b\,m\,n^2t^2 + 2\,b\,m\,n\,t^2 + 16\,b\,m\,t^2 - b\,n^2t^2 + 4\,b\,n\,t^2 + 8\,b\,t^2 - \\
& 2\,c^2m + c^2 - 4\,c\,m\,n\,t + 6\,c\,m\,t + 2\,c\,n\,t + 6\,c\,t - m^2n\,t^2 + 4\,m^2t^2 - 2\,m\,n^2t^2 + 4\,m\,n\,t^2 + 8\,m\,t^2 + \\
& n^2t^2 + 5\,n\,t^2 + 4\,t^2)/((b + 1)^2(m + 1)^2)
\end{aligned}
$$

$$
\begin{aligned}
t(b,m,n)^{coop} = {} & \bigl((a - c)(3\,b + 3\,m + n + 3\,b\,m - b\,n - 2\,m\,n - 2\,b\,m\,n + 3)\bigr)/(-b^2m^2n + 4\,b^2m^2 - \\
& 2\,b^2m\,n + 8\,b^2m - b^2n + 4\,b^2 - 2\,b\,m^2n + 8\,b\,m^2 - 2\,b\,m\,n^2 + 2\,b\,m\,n + 16\,b\,m - b\,n^2 + 4\,b\,n + \\
& 8\,b - m^2n + 4\,m^2 - 2\,m\,n^2 + 4\,m\,n + 8\,m + n^2 + 5\,n + 4)
\end{aligned}
$$

$$
\begin{aligned}
ED(b,m,n)^{coop} = {} & (2\,(a - c)^2(n + 1)^2(b + m + n + b\,m + m\,n + b\,m\,n + 1)^2)/(-b^2m^2n + 4\,b^2m^2 - \\
& 2\,b^2m\,n + 8\,b^2m - b^2n + 4\,b^2 - 2\,b\,m^2n + 8\,b\,m^2 - 2\,b\,m\,n^2 + 2\,b\,m\,n + 16\,b\,m - b\,n^2 + 4\,b\,n + \\
& 8\,b - m^2n + 4\,m^2 - 2\,m\,n^2 + 4\,m\,n + 8\,m + n^2 + 5\,n + 4)^2
\end{aligned}
$$

$$W(b,m,n)^{coop} = \big((a - c)^2(4b + 8m + n + 8bm - bn - 2mn - 2bmn + 5)\big)/(-b^2m^2n + 4b^2m^2 - 2b^2mn + 8b^2m - b^2n + 4b^2 - 2bm^2n + 8bm^2 - 2bmn^2 + 2bmn + 16bm - bn^2 + 4bn + 8b - m^2n + 4m^2 - 2mn^2 + 4mn + 8m + n^2 + 5n + 4)$$

➢ The equilibrium status of Cournot, Bertrand, and cooperation:

- Cournot competition:

$$W^{qq} = -\frac{(a - c)^2(25b + 5n - 4bn - 29)}{4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28}$$

$$CS^{qq} = \frac{(a - c)^2(-60b^3n + 375b^3 + 12b^2n^2 + 36b^2n - 435b^2 - 35bn^2 + 232bn - 584b + 25n^2 - 224n + 676)}{(4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28)^2}$$

$$ED^{qq} = \frac{4(a - c)^2(5b - 2n + 2bn - 6)^2}{(4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28)^2}$$

$$total\ emission\ tax^{qq} = \frac{2(a - c)^2(5b - 2n + 2bn - 6)(15b + 5n - 4bn - 18)}{(4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28)^2}$$

$$R_1^{qq} = \frac{(a - c)^2(16b^2n^3 - 120b^2n^2 + 225b^2n + 450b^2 - 40bn^3 + 294bn^2 - 600bn - 840b + 25n^3 - 178n^2 + 380n + 392)}{2(4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28)^2}$$

$$G^{qq} = (a - c)^2(176b^4n^3 - 360b^4n^2 - 6225b^4n + 22750b^4 - 80b^3n^4 + 496b^3n^3 - 4371b^3n^2 + 28425b^3n - 66050b^3 + 312b^2n^4 - 3479b^2n^3 + 18027b^2n^2 - 39816b^2n + 31580b^2 - 405bn^4 + 4983bn^3 - 21678bn^2 + 15876bn + 51432b + 175n^4 - 2192n^3 + 8376n^2 + 2016n - 40208) \;/\; 2(11b + 7n - 5bn + 15b^2 - 34)(4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28)^2$$

$$q_1^{qq} = \frac{(a - c)(n - 15b + 14)}{4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28}$$

$$q_2^{qq} = -\frac{(a - c)(25b + 7n - 4bn - 34)}{4b^2n - 25b^2 + 4bn^2 - 22bn + 4b - 5n^2 + 20n + 28}$$

$$p_1^{qq} = \frac{14*a + 14*c - 15*a*b + 19*b*c + 19*a*n + c*n - 25*b^2*c - 5*a*n^2 - 15*a*b*n - 7*b*c*n + 4*a*b*n^2 + 4*b^2*c*n}{4*b^2*n - 25*b^2 + 4*b*n^2 - 22*b*n + 4*b - 5*n^2 + 20*n + 28}$$

$$p_2^{qq} = -\frac{6*a - 34*c - 15*a*b + 11*b*c - 27*a*n + 7*c*n + 10*a*b^2 + 15*b^2*c + 5*a*n^2 + 27*a*b*n - 5*b*c*n - 4*a*b*n^2 - 4*a*b^2*n}{4*b^2*n - 25*b^2 + 4*b*n^2 - 22*b*n + 4*b - 5*n^2 + 20*n + 28}$$

- Bertrand competition:

$$W^{pp} = \frac{(a - c)^2(4b - 5n - bn + 5b^2n + b^3n - 20b^2 - 4b^3 + 29)}{b^3n^2 + 2b^3n - 23b^3 + 5b^2n^2 - 12b^2n - 21b^2 - bn^2 - 2bn + 32b - 5n^2 + 20n + 28}$$

$$CS^{pp} = ((a - c)\hat{}2\,(6\,b\hat{}6\,n\hat{}2 - 48\,b\hat{}6\,n + 96\,b\hat{}6 + 26\,b\hat{}5\,n\hat{}2 - 202\,b\hat{}5\,n + 392\,b\hat{}5 + 16\,b\hat{}4\,n\hat{}2 - 86\,b\hat{}4\,n + 88\,b\hat{}4 - 41\,b\hat{}3\,n\hat{}2 + 436\,b\hat{}3\,n - 1097\,b\hat{}3 - 45\,b\hat{}2\,n\hat{}2 + 372\,b\hat{}2\,n - 795\,b\hat{}2 + 15\,b\,n\hat{}2 - 216\,b\,n + 768\,b + 25\,n\hat{}2 - 224\,n + 676))/(b^3n^2 + 2b^3n - 23b^3 + 5b^2n^2 - 12b^2n - 21b^2 - bn^2 - 2bn + 32b - 5n^2 + 20n + 28)^2$$

$$ED^{pp} = \left(\frac{(a-c)(n-b+bn+2b^2n-8b^2+14)}{b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28} - \frac{2(a-c)(3b-5n-bn+5b^2n+b^3n-12b^2-3b^3+18)}{b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28} + \frac{(a-c)(9b-7n-3bn+6b^2n+2b^3n-24b^2-8b^3+34)}{b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28}\right)^2$$

$$\textit{total emission tax}^{pp} = \frac{2(a-c)^2(b+2n-b^2n-4b^2-b^3+6)(3b-5n-bn+5b^2n+b^3n-12b^2-3b^3+18)}{(b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28)^2}$$

$$R_1 = -\big((a-c)^2(-b^6n^3+14b^6n^2-73b^6n+128b^6-10b^5n^3+62b^5n^2-112b^5n+32b^5-23b^4n^3+110b^4n^2+14b^4n-574b^4+20b^3n^3-124b^3n^2+272b^3n-88b^3+49b^2n^3-302b^2n^2+403b^2n+838b^2-10bn^3+62bn^2-160bn+56b-25n^3+178n^2-380n-392)\big)/(2(b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28)^2)$$

$$G^{pp} = \big((a-c)^2(2b^{10}n^4+12b^{10}n^3-342b^{10}n^2+1656b^{10}n-2432b^{10}+28b^9n^4-68b^9n^3-1896b^9n^2+11424b^9n-18176b^9+129b^8n^4-977b^8n^3-447b^8n^2+18513b^8n-37408b^8+164b^7n^4-2149b^7n^3+11382b^7n^2-27633b^7n+23792b^7-296b^6n^4+1723b^6n^3+9921b^6n^2-88062b^6n+158434b^6-732b^5n^4+7807b^5n^3-23826b^5n^2-7110b^5n+98606b^5+22b^4n^4+1225b^4n^3-24189b^4n^2+120885b^4n-176930b^4+860b^3n^4-9363b^3n^3+22278b^3n^2+59811b^3n-217034b^3+318b^2n^4-4215b^2n^3+22833b^2n^2-52320b^2n+20436b^2-320bn^4+3741bn^3-8562bn^2-37812bn+115112b-175n^4+2192n^3-8376n^2-2016n+40208)\big)/(2(b+1)(9b-7n-3bn+6b^2n+2b^3n-24b^2-8b^3+34)(b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28)^2)$$

$$q_1^{pp} = \frac{(a-c)(n-b+bn+2b^2n-8b^2+14)}{b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28}$$

$$q_2^{pp} = \frac{(a-c)(9b-7n-3bn+6b^2n+2b^3n-24b^2-8b^3+34)}{b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28}$$

$$p_1^{pp} = (14a+14c-ab+33bc+19an+cn-22ab^2+ab^3+8ab^4+b^2c-24b^3c-8b^4c-5an^2+5ab^2n^2+ab^3n^2+4abn-6bcn-abn^2-11ab^2n-4ab^3n-2ab^4n-b^2cn+6b^3cn+2b^4cn)/(b^3n^2+2b^3n-23b^3+5b^2n^2-12b^2n-21b^2-bn^2-2bn+32b-5n^2+20n+28)$$

$$p_2^{pp} = -(6a-34c-9ab-23bc-27an+7cn-4ab^2+7ab^3+25b^2c+16b^3c+5an^2-5ab^2n^2-ab^3n^2+2bcn+abn^2+19ab^2n+2ab^3n-7b^2cn-4b^3cn)/\,(b\hat{}3\,n\hat{}2+2b\hat{}3\,n-23b\hat{}3+5b\hat{}2\,n\hat{}2-12b\hat{}2\,n-21b\hat{}2-b\,n\hat{}2-2bn+32b-5n\hat{}2+20n+28)$$

Cooperation:

$$W^{coop} = -\frac{(a-c)^2(n-4)}{4b+3n-bn-n^2+3}$$

$$CS^{coop} = \frac{(a-c)^2(b+1)(n-4)^2}{(4b+3n-bn-n^2+3)^2}$$

$$ED^{coop} = \frac{4(a-c)^2}{(4b+3n-bn-n^2+3)^2}$$

$$R_1^{coop} = \frac{(a-c)^2(n^3-8n^2+19n-8)}{2(4b+3n-bn-n^2+3)^2}$$

$$G^{coop} = \frac{(a - c)^2 (16\,b + 6\,n - 8\,b\,n + b\,n^2 - 6\,n^2 + n^3 + 12)}{(4\,b + 3\,n - b\,n - n^2 + 3)^2}$$

$$q_1^{coop} = q_2^{coop} = -\frac{(a - c)\,(n - 4)}{4\,b + 3\,n - b\,n - n^2 + 3}$$

$$p_1^{coop} = p_2^{coop} = -\frac{a - 4\,c - 4\,b\,c - 4\,a\,n + c\,n + a\,n^2 + b\,c\,n}{4\,b + 3\,n - b\,n - n^2 + 3}$$

References

Baltazar, R. and Brooks, M.R., 2001. The governance of port devolution: A tale of two countries. *Canadian Public Administration*, *42*(1), pp.108-132.

Bárcena-Ruiz, J.C. and Garzón, M.B., 2006. Mixed oligopoly and environmental policy. *Spanish Economic Review*, *8*(2), pp.139-160.

Beladi, H. and Chao, C.C., 2006. Does privatization improve the environment?. *Economics Letters*, *93*(3), pp.343-347.

Chen, P.S.L., Pateman, H. and Sakalayen, Q., 2017. The latest trend in Australian port privatisation: Drivers, processes and impacts. *Research in Transportation Business & Management*, *22*, pp.201-213.

Corbett, J.J. and Fischbeck, P., 1997. Emissions from ships. *Science*, *278*(5339), pp.823-824.

Cullinane, K., Ji, P. and Wang, T.F., 2005. The relationship between privatization and DEA estimates of efficiency in the container port industry. *Journal of economics and business*, *57*(5), pp.433-462.

Cullinane, K., Song, D.W. and Gray, R., 2002. A stochastic frontier model of the efficiency of major container terminals in Asia: assessing the influence of administrative and ownership structures. *Transportation Research Part A: Policy and Practice*, *36*(8), pp.743-762.

Czerny, A., Höffler, F. and Mun, S.I., 2013. Port competition and welfare effect of strategic privatization (No. 2013-13). Energiewirtschaftliches Institut an der Universitaet zu Koeln.

Dasgupta, M.K. and Sinha, D., 2016. Impact of privatization of ports on relative efficiency of major ports of India. *Foreign Trade Review*, *51*(3), pp.225-247.

De Fraja, G. and Delbono, F., 1989. Alternative strategies of a public enterprise in oligopoly. *Oxford Economic Papers*, *41*(1), pp.302-311.

Dore, A.J., Vieno, M., Tang, Y.S., Dragosits, U., Dosio, A., Weston, K.J. and Sutton, M.A., 2007. Modelling the atmospheric transport and deposition of sulphur and nitrogen over the

United Kingdom and assessment of the influence of SO 2 emissions from international shipping. *Atmospheric Environment, 41*(11), pp.2355-2367.

Eyring, V., Cionni, I., Lamarque, J.F., Akiyoshi, H., Bodeker, G.E., Charlton-Perez, A.J., Frith, S.M., Gettelman, A., Kinnison, D.E., Nakamura, T. and Oman, L.D., 2010. Sensitivity of 21st century stratospheric ozone to greenhouse gas scenarios. *Geophysical Research Letters, 37*(16).

Ferrari, C., Parola, F., & Tei, A., 2015. Governance models and port concessions in Europe: Commonalities, critical issues and policy perspectives. *Transport Policy, 41*, 60-67.

Geerlings, H., & Van Duin, R., 2011. A new method for assessing CO 2-emissions from container terminals: a promising approach applied in Rotterdam. *Journal of Cleaner Production*, *19*(6), 657-666.

Gibbs, D., Rigot-Muller, P., Mangan, J. and Lalwani, C., 2014. The role of sea ports in end-to-end maritime transport chain emissions. *Energy Policy, 64*, pp.337-348.

Habibi, M. and Rehmatulla, N., 2009. Carbon emission policies in the context of the shipping industry.

Haralambides, H.E., Cariou, P. and Benacchio, M., 2002. Costs, benefits and pricing of dedicated container terminals. *International Journal of Maritime Economics*, 4(1), pp.21-34.

International Maritime Organization (IMO), Third IMO Greenhouse Gas study 2014, *http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf*

Jinhwan K., 2015, Lessons From British Port Privatisation. *Journal of Distribution Science*, Vol. 13, No. 2, pp. 5–13.

Kawasaki, T., Tagawa, H., Watanabe, T. and Hanaoka, S., 2020. The effects of consolidation and privatization of ports in proximity: A case study of the Kobe and Osaka ports. *The Asian Journal of Shipping and Logistics*, *36*(1), pp.1-12.

Lam, J. S. L., & Notteboom, T., 2014. The greening of ports: a comparison of port management tools used by leading ports in Asia and Europe. *Transport Reviews, 34*(2), pp. 169-189.

Lee, D., Lim, S. and Choi, K., 2017. Port privatization under Cournot vs. Bertrand competition: a third-market approach. *Maritime Policy & Management*, *44*(6), pp.761-778.

Leonard F. S. Wang and Ya-chin Wang and Lihong Zhao, 2009, Privatization and the Environment in a Mixed Duopoly with Pollution Abatement, *Economics Bulletin, 29*(4), pp. 3112-3119.

Ma, W., Hao, S., Ma, D., Wang, D., Jin, S. and Qu, F., 2021. Scheduling decision model of liner shipping considering emission control areas regulations. *Applied Ocean Research*, *106*, p.102416.

Matsushima, N. and Takauchi, K., 2014. Port privatization in an international oligopoly. *Transportation Research Part B: Methodological, 67,* pp.382-397.

Midoro, R., Musso, E. and Parola, F., 2005. Maritime liner shipping and the stevedoring industry: market structure and competition strategies. *Maritime Policy & Management, 32*(2), pp.89-106.

Notteboom, T. E., 2006. The time factor in liner shipping services. *Maritime Economics & Logistics*, *8*(1), 19-39.

Notteboom, T., 2011. The impact of low sulphur fuel requirements in shipping on the competitiveness of roro shipping in Northern Europe. *WMU Journal of Maritime Affairs, 10*(1), pp.63-95.

Notteboom, T.E., 2009. Complementarity and substitutability among adjacent gateway ports. *Environment and Planning A*, *41*(3), pp.743-762.

Pagano, A. M., Wang, G. W., Sánchez, O. V., & Ungo, R., 2013. Impact of privatization on port efficiency and effectiveness: results from Panama and US ports. *Maritime Policy & Management*, *40*(2), 100-115.

Pal, R. and Saha, B., 2015. Pollution tax, partial privatization and environment. *Resource and Energy Economics, 40,* pp.19-35.

Pian, F., Xu, L., Chen, Y. and Lee, S.H., 2020. Global emission taxes and port privatization policies under international competition. *Sustainability*, *12*(16), p.6595.

Reusser, C.A. and Pérez Osses, J.R., 2021. Challenges for zero-emissions ship. *Journal of Marine Science and Engineering*, *9*(10), p.1042.

Saxe, H. and Larsen, T., 2004. Air pollution from ships in three Danish ports. *Atmospheric Environment, 38*(24), pp.4057-4067

Sheng, D., Li, Z. C., Fu, X., & Gillen, D., 2017. Modeling the effects of unilateral and uniform emission regulations under shipping company and port competition. *Transportation Research Part E: Logistics and Transportation Review*, *101*, 99-114.

Sheng, D., Li, Z.C., Fu, X. and Gillen, D., 2017. Modeling the effects of unilateral and uniform emission regulations under shipping company and port competition. *Transportation Research Part E: Logistics and Transportation Review*, *101,* pp.99-114.

Song, D. W., 2002. Regional container port competition and co-operation: the case of Hong Kong and South China. *Journal of Transport Geography*, *10*(2), 99-110.

Song, S., 2014. Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port. *Atmospheric Environment*, *82,* pp.288-297.

Tongzon, J. and Heng, W., 2005. Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). *Transportation Research Part A: Policy and Practice, 39*(5), pp.405-424.

Tseng, P.H. and Pilcher, N., 2016. Exploring the viability of an emission tax policy for ships at berth in Taiwanese ports. *International Journal of Shipping and Transport Logistics, 8*(6), pp.705-722.

Tzannatos, E., 2010. Ship emissions and their externalities for the port of Piraeus–Greece. *Atmospheric Environment*, *44*(3), pp.400-407.

Villalba, G. and Gemechu, E.D., 2011. Estimating GHG emissions of marine ports—the case of Barcelona. *Energy Policy, 39*(3), pp.1363-1368.

Wang et al., 2014, Hong Kong Pushes China to Co-Establish Emissions Control Area. Mondaq Business Briefing. Retrieved Janarury 11, 2017, from *http://www.mondaq.com/x/315664/Marine+Shipping/Hong+Kong+Pushes+China+To+CoEstablish+Emissions+Control+Area.*

Wang, L.F. and Wang, J., 2009. Environmental taxes in a differentiated mixed duopoly. *Economic Systems*, *33*(4), pp.389-396.

Wang, L.F., Wang, Y.C. and Zhao, L., 2009. Privatization and the environment in a mixed duopoly with pollution abatement. *Economics Bulletin, 29*(4), pp.3112-3119.

World health organization, Air quanlity guidelines for Europe, second edition, *http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf*

Xiao, Y., Ng, A.K., Yang, H. and Fu, X., 2012. An analysis of the dynamics of ownership, capacity investments and pricing structure of ports. *Transport Reviews, 32*(5), pp.629-652.

Xu, L., Cho, S. and Lee, S.H., 2016. Emission tax and optimal privatization in Cournot–Bertrand comparison. *Economic Modelling, 55*, pp.73-82.

Zheng, S., Ge, Y. E., Fu, X., Nie, Y. M., & Xie, C.,2017. Modeling collusion-proof port emission regulation of cargo-handling activities under incomplete information. *Transportation Research Part B: Methodological*, 2017.

Zhou, Y., Zhang, Y., Ma, D., Lu, J., Luo, W., Fu, Y., Li, S., Feng, J., Huang, C., Ge, W. and Zhu, H., 2020. Port-related emissions, environmental impacts and their implication on green traffic policy in Shanghai. *Sustainability*, *12*(10), p.4162.

Conclusions

In this final part of the dissertation, the primary research findings are briefly presented and then discussed in terms of their theoretical and managerial contribution to competition and cooperation in the shipping and port industry and the challenges they present for the future research agenda on the related topics.

Chapter 1 identified bottleneck issues in port areas due to a lack of coordination, initially resulting from the conflicting interests of different actors. So, a cooperative incentive mechanism is briefly proposed and tested by comparing the two possible statuses of two partner coalitions. The paper also addressed the specific coordination problem of the possible mismatches in the schedules of vessels and rail shuttles. The risks of incurring synchronization problems have increased due to the increased vessel and call sizes, poor liner schedule integrity, lengthy timetabling in rail, rigid and often full railway schedules, and the potential underperformance of ports and terminals. Based on the incentive principle mentioned above, an incentive mechanism is proposed to reduce the unpunctuality issues in a two-partner transport chain. Such an approach can open opportunities to shift the allocated profit towards the part that adapted its schedule to the other actor to reduce further delays or even eliminate the delay if enough incentive exists. The method will particularly reward the more flexible partner compared to the result of the original Shapley Value.

This study contributes to the development of maritime hinterland transport chains. Although the concept of integrated supply chains has been widely recognized, the bounded rationality of actors in the port community can still lead to sub-optimal results, which is also a central problem for exiting the coalition. The conflicting interests and individual behavior of different actors can compromise the performance of the whole chain. The current development in maritime transport research indicates that individual actors should collaborate and be fully integrated into maritime supply chains.

From the *management point of view*, this discussion contributes to the studies of the vertical integration of shipping lines and hinterland transport operators and shows the need for taking into account the incentives/compensations to let either party adapt to the other for a smooth intermodal chain. In practice, there is a trend of logistic integration between the ocean carrier and inland logistics (not limited to the railway operator/company), such as the collaboration between CEVA logistics and CMA CGM. The mechanism could serve as the principle of a performance-based contract between the shipping line and the inland logistics, that the flexible partner receives a higher profit share based on its excellent punctuality performance, which should be aligned to improve intermodal coordination and reduce delays.

From the perspective of *policymakers*, this discussion develops the cooperative framework for the model coordination problem by connecting the consensus of academic research with the actual implementation at an operational level. Such mechanisms can facilitate collaborations, which offer opportunities for better economic growth and trade facilitation, but also face many challenges, such as the insufficient infrastructure to support the collaboration, the rigid regulation regarding access to the infrastructure, and the potential unfair competition caused by the collaboration. This requires the policymakers to play a critical role in creating an environment that can encourage collaboration, regulate the industry, and support the resilience of the supply chain.

Obviously, this conceptual discussion could be extended by using real operational data to validate the incentive mechanism. The related institutional and governance issues also present possible pathways for further research.

The next Chapter is the continuation of the core idea of incentive mechanism or benefit allocation but in the context of the shipping alliance.

Chapter 2 reviewed the advantages of shipping alliances and cooperative game theory applications in various industries, with a specific focus on logistics collaboration. Using a scenario with multiple carriers in the shipping alliance that are running similar liner services on a main route, we presented a theoretical framework on voyage integration aimed at minimizing total costs (summation of direct transport cost and penalty cost). Based on the features of the model optimization, a certain cost saving can be obtained, but the individual carrier may not be satisfied by the global optimal arrangement. So, a proper benefit allocation method is needed to be integrated into the optimization model to prevent the carrier from rejecting the arrangement. Two follow-up solutions are proposed to balance the positive-gain carriers and the negative-gain carriers, including negotiation (without changing the overall optimal arrangement) and the re-allocation of the benefits by restoring certain "highest penalty cost" voyages (by changing the previous optimal arrangement).

On the *theoretical level*, this paper contributes to the understanding/literature of the voyage integration (synergy) among the carriers in the shipping alliance and further cost savings allocation in return for promoting those integrations by the pro-active shipping companies. It also provides insights into the stability research in shipping alliances by achieving a balance between efficiency and flexibility.

For *business practice*, **Shipping lines** can benefit from voyage integration by potentially reducing their operational cost, not only by cutting off certain fixed costs linked to their voyages but also by enjoying the benefits from economies of scale by sharing the vessel capacity. In addition, this can also benefit the stability and efficiency of the shipping alliance, which leads to improved service quality. **Port operator and Port Authority**, which does not directly gain from the voyage integration, can also benefit, such as more scheduled voyages and more "dense" cargo handling, which can directly improve the operation efficiency and resource allocations. But, at the same time, they may face challenges, such as delays due to insufficient infrastructure development and capacity expansion, caused by the possible enlarged vessels in the voyage integration scenario and the further requirements of collaboration between the Port Authority and Port Operator, particularly in the port investments.

For the *policymaker*, the voyage integration and benefit allocation can contribute to not only the growth and competitiveness of the maritime and logistic sector but also environmental sustainability. A clear compromise between collective rationality and individual rationality was observed, which is important not only for the participants (shipping lines) but also for policymakers in identifying the best practices for maximizing the benefits of collaborations and minimizing the risks. They need to create a balanced regulatory environment for the shipping alliances, ensuring enough room to promote collaboration and not cross the line of the antitrust law.

Besides, there is room for further research: (1) exploring the other benefits of the voyage integration, other than the cost savings, (2) combining the benefits from vertical integration to form a supply chain perspective, (3) how the different features of the carriers and cost structure can affect the sharing of cost savings, (4) which governance set-up can provide a stronger control with this mechanism along the chains.

The next **Chapters 3, 4, and 5** are all based on the context of mixed duopoly/oligopoly, and they all highlight the effects of external issues/policies on the interaction matrix of private & public interests and competition & cooperation.

Chapter 3 presented a mixed duopoly model with differentiated service to investigate the effects of private level and service differentiation in various settings and find feasible combinations of private level and service differentiation levels to promote integration from previously (multiple) competing statuses by comparing the revenues or profits between the cooperation scenario and the competition scenarios. A preliminary application of this model is presented on the competition between Shenzhen Port and Hongkong Port to show how the theoretical results can help the government to guide the pathway toward port integration.

On *the theoretical level*, the outcomes of this paper can serve as useful inputs for ongoing public policy discussions on port competition and cooperation and a response to the current trend of port integration. The paper provides an additional argument of service differentiation/similarity, private/public-oriented objectives, and feasible combinations of both factors to promote integration. In previous studies, a higher service similarity normally implies a “decrease in the service price and capacity” in competition and cooperation due to fierce homogeneous competition. In contrast, we found that under certain circumstances, increasing service similarity may lead to the opposite results. However, an increasing service similarity will damage the profitability of both ports in all competition and cooperation scenarios, which is consistent with earlier studies. The effect of the public/private-oriented objective of the PA differs in the considered scenarios. In other words, our findings do not always support the notion that “port privatization will raise the price and lower the cargo volume”. Under Cournot competition, the capacity and service price of both ports is not affected by the private-oriented objective, which can only affect the partial public port`s revenue. Under Bertrand competition, q-p competition, and cooperation, an increasing level of private objective always increases service price but has a different influence on the cargo volume. It also benefits the private port since it will always transfer certain revenue from the partial public port to the private port if they decide to merge. Under the cooperation scenario, service similarity compromises both ports` revenues and capacity but does not affect the joint price since the monopolistic alliance can control the price regardless of the service similarity/differentiation. An increasing private objective orientation of the PA can raise the service price and decrease the cargo volume, which is consistent with previous studies.

For *business practice,* the result of the study can help the **private Port (Operator)** to identify the opportunity to seize growth in throughput/infrastructure and expand market share by integrating with the semi-public port, enhance its profitability through the necessary transfer of profit, and provide a better understanding of the potential benefits and challenges for the integration. For the **Port Authority**, understanding the conditions and scenarios (quantity or price or mixed competition) that favor cooperation is essential for effective partnership development, and it is also feasible to develop an agreement that offers profit/risk-sharing arrangement or other compensation to make the integration more attractive (to solve the problem of shortage in port investments), so as to improve infrastructure development and keep up with evolving industry need. For the **shipping lines**, this paper can provide certain insights into their decision-making regarding the negotiation strategies with the port/terminal.

For the *policy makers/government*, this study`s result could be used to shape its policies related to the plan of port integrations from the competing scenarios and appears to align with the expectation of a trend toward port integration. For instance, the government can design an incentive mechanism that encourages cooperation between public and private entities for joining a strategic alliance by cross-subsidizing/compensating in certain scenarios. On the other hand, the two ports will merge naturally without the need for a government "push" in some other scenarios. In addition, the government should, to some extent, balance its objectives between maximizing social welfare (throughput) and the concerns about monopoly (anti-trust policy). By applying the theoretical results in reality, the government/port authorities can position themselves in the context of the port competition and use that map to find feasible pathways to foster a potential port integration.

The presented study faces some methodological simplifications and limitations. First, we assumed linear demand and cost functions for simplification, which may deviate from reality (which is further discussed at the end of Chapter 3.4). So, there is still a need to check the conclusions based on other suitable types of demand/cost functions, such as non-linear demand functions with conjectural variation and stochastic demand functions. Second, cooperation between two oligopolistic PAs may lead to a monopoly, which concerns the government. Finally, the inclusion of some practical issues in the models will help its robustness (e.g., global port operators operating in both ports or the same municipal shares in both ports, etc.).

Chapter 4 investigated vertical integration between a shipping line and a port terminal in the context of a mixed duopoly. This paper adopts an economic model to reveal the effects of the new expansion on each participant, including a landlord port (public port authority and private port operator), a private port, an integrated shipping line, and many other rival shipping lines, by comparing the baseline (non-integrated scenario) with the integrated scenario. The results indicate that vertical integration (new expansion invested by the port and shipping line) could be the source of the synergy of the maritime transport chain by raising the port capacity, the shipping line's output, and social welfare.

On the *theoretical level*, the model result suggests a higher integration level can result in a higher port capacity and throughput, higher port charge for the landlord port A, and higher output (cargo volume) of the integrated shipping line, which is consistent with the results from Zhu et al. (2019). On the other hand, private port operator B may suffer a loss because of the lower optimal port charge in the integration scenario with the uncertainty on its throughput changes due to integration. The numeric example, serving as a supplement for the theoretical results, shows that the integration can raise the output and profit of the participating shipping line, outperforming not only itself in the baseline scenario but also the rival shipping lines in the vertical integration scenario. In other words, the participation of shipping lines in vertical integration with terminals can help the shipping line gain certain market power at the cost of other non-integrated rival shipping lines.

For *business practice*, the **Port Operator**, its competitive position, and associated risk with the integration could be evaluated based on this study, and the final optimal investment decision and pricing strategy can be obtained. By allowing the SL to be involved in the new capacity investment, the port operator can lift its throughput and improve the facilities' efficiency/utilization, solve the problem of the shortage of investment, and enhance its competitiveness and market position. However, as mentioned in the study, the port operator may also face reduced profitability and overcapacity risk(due to extra capacity added) and weakened autonomy in pricing strategy. For the **shipping lines**, the results can help the SL understand that, on one hand, involvement in the new capacity investment can gain more control on the port management to improve its logistics performance and generate more profits not only from the traditional shipping service but also from the terminal operation, seize more market power allowing SL to have a competitive advantage over rivals; on the other hand, vertical integration may lead to concerns regarding the financial risk and uncertainty, overcapacity risks, flexibility challenges (dynamics of shipping alliances, which is shared with port operator), and worries about the "fair" competition regulations (which is shared with port operator).

For **Port Authority***/policy makers/government*, this study can help them better understand that allowing SL to engage in new capacity investment can solve the urge on the throughput concerns and the stagnant infrastructure development, as well as the local economic development, so as to improve the social welfare and help the port gain better market competitiveness; At the same time, the PA also need address the operational challenges, such as the flexibility issues (dynamic of shipping alliances), over-dependency issues (weaken port`s competitiveness), and potential overcapacity issues; And the policy maker/government may need to establish a clear regulatory framework to monitor the vertical integration, related to market power, competition, and ownership restriction, to maintain a competitive environment, without losing too much autonomy.

There are some simplifications and limitations of the proposed modeling exercise: (1) the linear demand function (the limitation is addressed in the last part of Chapter 3.4), (2) the linear delay cost function (It does not reflect the effects of shipping line`s economies of scale on delay cost), (3) assumption of shipping line directly investing in the new capacity (in practice, this investment is usually made by the subsidiary/sister company of the shipping line), (4) allocation of the profit from the expansion based on the share of investment (In practice, the share is mainly decided by the bargaining process among the terminal operator, port authority/government, and shipping lines), (5) the assumption of same capacity of the two initial ports (6) constant marginal cost of two ports (In practice, different ports may adopt different cost structure to provide differentiated service)

Chapter 5 modeled emission taxes in combination with the privatization level of the port in view of assessing their interplay in different port competition and cooperation settings and considering different levels of service similarity between ports and the share of port operations in total emissions. To be specific, this chapter compared the parameters, such as optimal emission tax, privatization level, service differentiation, etc., in three different scenarios, named Cournot competition, Bertrand competition, and cooperation. A simple numeric example, which is applied in Shenzhen Port and Hongkong Port, presents the dynamics of each parameter based on the theoretical results.

On the *theoretical level*, this study investigated the combined effect of the port privatization and possible emission tax on port competition/cooperation and environment and highlights the inclusion of a portion of port pollution (other than the ship pollution at port) and strategic cooperation scenario. The result shows that (1) The government should charge a higher emission tax in cooperation scenarios than in other competition scenarios, and the emission tax should always be lower than the environmental damage it causes. (2) Privatization of the landlord port in the competition has a non-monotonous effect on the environmental damage since it, on the one hand, directly reduces the cargo volume/emission. On the other hand, it also reduces the optimal emission tax. (3) As for the potential cooperation from the competition status, the landlord will need to compensate for the profit loss of the private port when opting for a strategic alliance. (4)

The Government should carefully evaluate the decision on port mergers due to the tradeoff between social welfare and environmental damage.

For the **Port Authority**, this study offers insights into the optimal level of privatization and the optimal emission tax in different scenarios, and PA can use this information to shape its own decisions regarding social/economic benefits, environmental sustainability, and regulatory compliance. For the *policymakers*, based on the result of the study, it shows that adjusting the port privatization and emission tax in various scenarios will help the government to address the environmental challenges and the economic sustainability issue of the port combined. Policymakers must carefully navigate the trade-off between social welfare, environment protection, and port profitability, so the decision regarding port ownership reform and emission tax levels and strategic cooperation between the semi-public and private port should be carefully assessed to minimize the externalities without unduly burdening business.

The proposed modeling exercise comes with some simplifications and limitations. The choice of the inverse demand function, the cost function, the consumer surplus function, etc., may affect the final outcomes. Also, in real life, it might be convenient to impose a uniform emission tax for all domestic ports. When it comes to international ports, however, there are many tensions between different nations regarding the fairness of emission taxes, and this may result in not reaching a level playing field in port competition, leading to unnatural cargo shifts between ports. Furthermore, it is also interesting to investigate how the optimal private level and emission tax will be affected by a third market (transit market).

In the end, as mentioned in the introduction, the papers presented in this Ph.D. thesis aspire to provide a better understanding of how to improve the competitiveness of ports and carriers through the lens of competition and cooperation. Obviously, not all current issues in cooperation and competition in the port and shipping industry have been addressed within the five presented chapters. Still, the developed models and applied methodologies and the resulting findings are not solely relevant to the analyzed research settings. They can contribute to a more effective, formal port/shipping competition/cooperation analysis and to the continuous evaluation of those strategic actions and the results with regard to the contribution to the competitiveness of ports and shipping lines.