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**MARKET STRUCTURE IN THE CONTAINER LINER SHIPPING
INDUSTRY: AN ANALYSIS OF THE MARITIME NETWORK, PORT
EFFICIENCY AND COMPETITION**

By

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Structure de marché du secteur du transport maritime de lignes régulières : Une analyse du réseau maritime, de l'efficacité portuaire et de la concurrence

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Titre : Structure de marché du secteur du transport maritime de lignes régulières : Une analyse du réseau maritime, de l'efficacité portuaire et de la concurrence

Mots clés : Transport maritime de lignes régulières, MS-VAR, Théorie des graphes, Analyse d'Enveloppement des Données, Compétition

Résumé : La présente thèse a pour ambition d'évaluer la structure de marché du transport maritime de lignes régulières, en particulier au regard de l'intégration maritime au sein de l'ASEAN. Les problématiques principales abordées dans le cadre de ce travail sont liées aux déterminants fondamentaux des taux de fret, à la connectivité maritime, à l'efficacité portuaire et à la compétition sur les routes maritimes. Les analyses reposent sur l'utilisation d'outils méthodologiques précis tels que les modèles Markov-Switching Vecteur Autorégressifs, la Théorie des graphes, l'Analyse d'enveloppement des données, l'Analyse en composantes principales et le partitionnement de données. Les résultats permettent d'identifier trois cycles économiques entre 2003 et 2017, et montrent que le développement de la flotte a eu des effets négatifs non négligeables sur les taux de fret.

L'étude illustre que le classement portuaire change en fonction des différents coefficients de centralités. Les résultats de l'analyse de la modularité confortent l'intuition d'une bonne connectivité maritime intra-ASEAN. De plus, le réseau maritime de l'ASEAN possède des attributs similaires aux flux d'échanges commerciaux. Cette analyse de l'intégration maritime régionale est complétée par une étude plus approfondie permettant de visualiser les ports les plus efficaces de la communauté. Une dernière analyse de la compétition sur les routes maritimes met en avant les trajets sur lesquels le nombre d'entreprises en concurrence est le plus élevé. Au final, la thèse permet de mieux comprendre comment est organisé le transport de conteneurs au niveau mondial et régional, et comment s'effectue l'intégration maritime de l'ASEAN dans la chaîne d'approvisionnement mondiale.

Title : Market structure in the Container Liner Shipping Industry: An analysis of the maritime network, port efficiency and competition

Keywords : Container Shipping, MS-VAR, Graph Theory, Data Envelopment Analysis, Competition

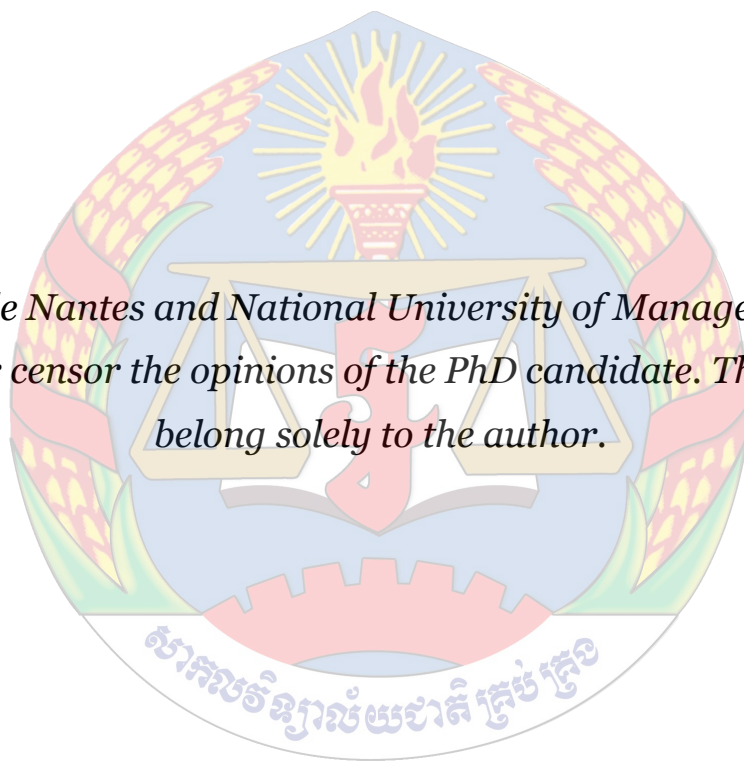
Abstract: This dissertation aims to analyze the structure and the evolution of the Container Liner Shipping Industry by paying particular attention to the maritime integration of ASEAN member states. The factors behind freight rates, maritime connectivity, port efficiency and competition on maritime routes are the central topics of research. Methodological tools such as Markov-Switching Vector Autoregressive Approach, Graph Theory, Data Envelopment Analysis, as well as Principle Component Analysis and Cluster Analysis are employed. The findings from the research show that between 2003 and 2017 three economic cycles occurred and that fleet development had the most profound negative impact on freight rates. The Network Analysis of 153 ports confirms a hub-and-spoke nature of the shipping network. The study illustrates that port rankings change according to different centrality measures.

It also demonstrates that ASEAN member states form a cluster of interconnected ports, and their shipping network has the same features as the intra-regional country exports. To complete the analysis of ASEAN maritime integration, this research outlines the most efficient ports within the community and the optimum container handling capacity. Competition on maritime routes, with respect to the country and region of origin and the destination, is also evaluated by highlighting the most concentrated routes in terms of number of competing firms. Moreover, the findings of this dissertation provide key answers to understanding how the industry is organized at global and regional levels, and the extent of maritime integration of the ASEAN region within the global supply chain.

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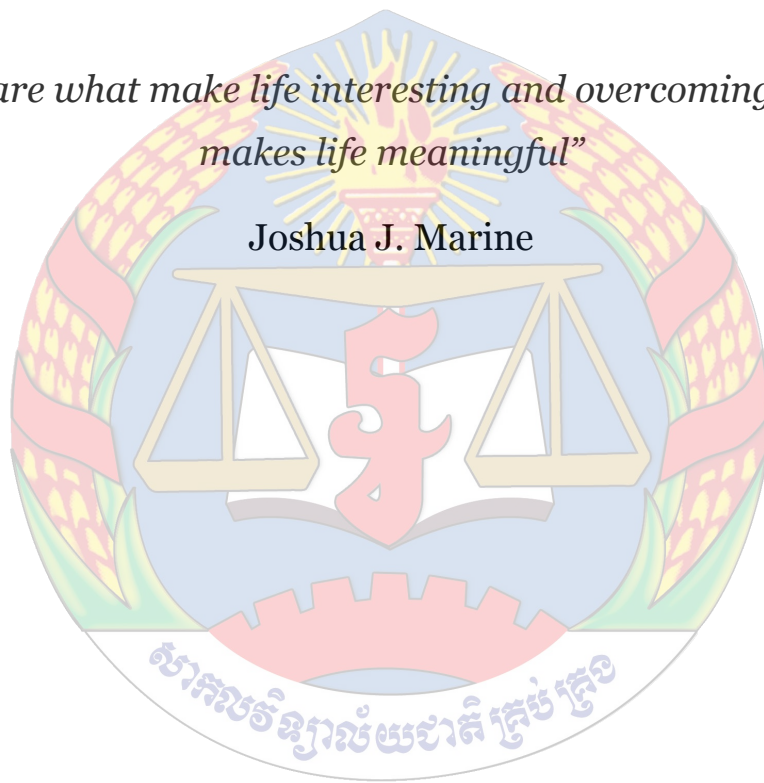
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“Challenges are what make life interesting and overcoming them is what makes life meaningful”

Joshua J. Marine



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Résumé Substantiel

Depuis la mise en place des premiers conteneurs intermodaux par Malcom Purcell McLean en 1956, la quantité de marchandises transportées par conteneurs a augmenté de façon exponentielle. La conteneurisation a révolutionné le commerce international en permettant aux entreprises de transporter des produits finis et intermédiaires d'une manière efficace et en toute sécurité. Les ports de conteneurs sont non seulement des éléments importants pour la compétitivité commerciale d'un pays ou d'une région, mais ils jouent également un rôle non négligeable dans le renforcement de l'intégration économique au sein d'une région.

..L'objectif principal de la présente thèse est d'analyser la structure et l'évolution du secteur du transport maritime de lignes régulières, en particulier au regard de l'intégration maritime au sein de l'ASEAN¹, en répondant aux quatre questions suivantes : Quels sont les principaux déterminants des taux de fret dans une période de croissance d'activités ou de crise ? Comment le réseau de transport de conteneurs est-il organisé au niveau mondial et au sein de l'ASEAN et quel est le rôle des différents ports dans ce réseau ? Quels sont les ports les plus efficaces de l'ASEAN et quelle est leur capacité optimale de manutention des conteneurs ? Quel est le niveau de concurrence sur les routes maritimes intrarégionales et interrégionales ? Pour répondre à ces questions, la thèse se structure en quatre chapitres.

..Le **premier chapitre** est consacré à l'analyse des fondamentaux du taux de fret en examinant notamment la relation entre ce taux et les variables suivantes : le prix du pétrole, le développement de la flotte de porte-conteneurs, l'activité économique mondiale et les revenus générés. Ce chapitre permet de comprendre les conséquences de la crise des subprimes sur le commerce conteneurisé ; crise qui a marqué la fin de l'un des cycles les plus profitables pour l'industrie. En effet, en 2009 les exportations conteneurisées ont chuté de 11%, ce qui a entraîné une baisse brutale des taux de fret. Depuis lors, les compagnies maritimes font face à une faible croissance de la demande et connaissent des difficultés pour rester solvables.

Des recherches antérieures indiquent qu'un cycle économique dans le transport maritime de lignes régulières dure en moyenne 7,5 ans et que les taux de fret ont un impact positif sur les

¹ Association des Nations de l'Asie du Sud-Est

revenus des entreprises maritimes. Cependant, la littérature relative aux taux de fret s'est presque exclusivement concentrée sur le coût du transport des matières premières et peu d'études ont utilisé l'approche VAR pour analyser la relation entre les variables clés du marché du transport de conteneurs. Ce chapitre vise à déceler les cycles économiques en utilisant des modèles de Markov-Switching Vecteur Autorégressifs (MS-VAR) fondés sur l'hypothèse de l'existence de deux régimes. Cette approche MS-VAR nous fournit des estimations précises concernant la durée de chaque régime ainsi que les probabilités associées à un changement de régime, et elle permet d'identifier les différents cycles économiques sur la période observée. L'indice des taux de fret de la Chine² (CCFI) est la variable de référence de l'étude. L'utilisation de fonctions de réponses aux chocs dans les modèles VAR structurels à changements de régimes markoviens nous donne des estimations cohérentes et efficaces de la réaction du CCFI à différents facteurs en fonction de l'état de l'industrie.

Les résultats de la recherche montrent que les deux régimes sont très persistants. Les probabilités d'un changement du régime 1 vers le régime 2, et inversement, sont très faibles, 18,5% et 17%, respectivement. Le régime 1 est caractérisé par un faible niveau d'activité économique, une forte volatilité des taux de fret, alors que le second régime est défini par des taux de fret élevés et stables. De mai 2003 à février 2017, trois grands cycles économiques ont été identifiés. Le premier est caractérisé par une période de croissance longue qui dure jusqu'en août 2008. Le cycle suivant est un cycle de transition qui dure 6 ans. Le troisième et dernier cycle est caractérisé par des taux de fret très bas, des revenus faibles et une augmentation substantielle de la taille de la flotte mondiale. Ce troisième cycle correspond à « la nouvelle normalité », appellation retenue par le Forum maritime danois et par la Chambre internationale de la marine marchande pour définir l'état actuel du commerce de conteneurs qui est caractérisé par une croissance du commerce international inférieure à la croissance économique mondiale. Les fonctions de réponses aux chocs montrent que le développement de la flotte mondiale a un impact négatif profond sur les taux de fret. Son effet est plus prononcé dans le régime de crise. Les revenus des opérateurs de porte-conteneurs et le prix du pétrole ne sont quant à eux significatifs que dans le second régime où ils ont un effet positif sur le CCFI. L'activité économique mondiale a une influence mineure sur le CCFI dans le régime de crise. Ces résultats confirment que la surcapacité dans l'industrie a un effet

² China Containerized Freight Index (CCFI)

négatif notable sur les taux de fret. Contrairement à nos attentes, le prix du pétrole ne semble être significatif que dans un contexte de croissance du secteur.

Le deuxième chapitre analyse le réseau créé par le transport de conteneurs au niveau des ports, pays et régions. Il examine également le niveau d'intégration maritime dans la chaîne d'approvisionnement mondiale des États membres de l'ASEAN. De plus, une étude de cas comparant les flux de valeur des exportations et les flux de porte-conteneurs au sein de l'ASEAN+3³ est réalisée, et des informations importantes sont ensuite fournies sur la structure du commerce et sur l'intégration maritime au sein de la communauté.

Cette recherche contribue à la littérature en fournissant une analyse complète de différents types de réseaux, au niveau des ports et des pays, en utilisant un échantillon de 6 410 routes maritimes qui relient 153 ports appartenant à 50 pays et incluant de fait tous les principaux ports de l'ASEAN+3. A partir de cette base de données, cinq réseaux pondérés dirigés ont été plus précisément construits: le « Réseau portuaire maritime », le « Réseau maritime au niveau des pays », le « Réseau portuaire ASEAN+3 », le « Réseau maritime ASEAN+3 au niveau des pays » et le « Réseau des flux d'exportations au sein de l'ASEAN+3 ». Dans les quatre premiers réseaux, les liens entre chaque paire de ports ou pays sont pondérés en fonction du nombre de voyages multiplié par la taille moyenne des navires opérant sur la route maritime. Dans le dernier réseau, les poids des liens sont pondérés par rapport à la valeur totale des biens exportés entre les pays de l'ASEAN+3. Différentes mesures de centralité ont été calculées afin de mettre en évidence le rôle des différents ports et pays au sein de ces réseaux. En outre, un algorithme de classification a été utilisé pour faire apparaître les communautés étroitement interconnectées et pour établir si des communautés telles que l'ASEAN sont identifiables en tant que groupes spécifiques.

Des recherches antérieures, basées sur la théorie des graphes, avaient révélé que le réseau de transport de conteneurs a une structure en étoile. Il est dominé par de grands ports ayant des connexions directes entre eux. La théorie des graphes fournit des outils utiles pour déterminer le rôle des différents ports dans les réseaux maritimes au niveau régional ou mondial. Par exemple, les mesures de centralité mettent en lumière la hiérarchie entre les ports et montrent comment varie l'importance d'un port donné. Plus précisément, un port présentant un coefficient de degré de

³ ASEAN+3 est une communauté rassemblant les pays de l'ASEAN ainsi que la Chine, le Japon et la Corée du Sud.

centralité élevé entretient de fortes connexions avec de nombreux ports. Un coefficient d'intermédiarité important indique que le port joue le rôle d'un hub régional et constitue un point de passage obligatoire pour de nombreux ports appartenant au réseau. Le coefficient de proximité montre la capacité d'un port à atteindre rapidement tous les autres ports du réseau.

Les résultats de ce chapitre confirment la structure en étoile du réseau maritime mondial. Au sein du réseau portuaire, Singapour, Hong Kong, Ningbo-Zhoushan, Shanghai et Shenzhen sont identifiés comme des hubs majeurs. Certains ports comme Said, Balboa et Belawan ont des coefficients de degré de centralité relativement faibles ainsi que des coefficients d'intermédiarité et de proximité élevés. Cela signifie qu'ils bénéficient de leur position géographique stratégique et qu'ils ont des connexions avec un nombre important de ports situés à la périphérie du réseau. Lorsque nous agrégeons les données au niveau des pays, il est observé que les États européens, ainsi que l'Amérique du Nord et du Sud, forment des communautés liées. La Chine, les États-Unis, les Pays-Bas et le Japon sont des ponts importants pour relier ces différentes communautés.

L'étude de la connectivité entre les ports de l'ASEAN+ 3 révèle que les ports japonais et celui de Hong Kong sont les plus centraux pour la circulation de navires. Cependant, Shanghai et Singapour ont les coefficients d'intermédiarité les plus élevés, ce qui en fait des points de passage importants reliant les nombreux ports de ce réseau ASEAN+3. Sur la base d'une analyse de la modularité, une communauté de ports regroupant une grande partie des ports de l'ASEAN a été identifiée, la République des Philippines étant cependant le seul pays maritime de l'ASEAN à ne pas disposer d'aucun port au sein de cette communauté. Ce résultat conforte l'intuition d'une bonne connectivité maritime intra-ASEAN. Enfin, l'analyse comparative entre les flux d'exportations totaux et les interactions portuaires au sein de l'ASEAN+3 démontre que les deux réseaux (i.e. ASEAN et ASEAN+3) présentent des caractéristiques similaires et que la position du pays dans le réseau maritime influence aussi sa compétitivité commerciale.

Le troisième chapitre analyse l'efficacité des ports de conteneurs de l'ASEAN. Le transport de conteneurs est un secteur stratégique où la taille influence la rentabilité. Les possibilités de réaliser des économies d'échelle, en transportant un grand nombre de conteneurs en un seul voyage, ont poussé les compagnies maritimes à être plus efficaces en construisant des navires de plus en plus grands et performants. Depuis 1997, la taille maximale d'un porte-conteneurs a triplé. Ces

tendances ont, en retour, une implication pour les terminaux, qui doivent améliorer leur efficacité et leur productivité afin d'éviter les embouteillages et les goulots d'étranglement.

La plupart des études portant sur l'efficacité portuaire appliquent la méthode non paramétrique appelée « Analyse d'enveloppement des données » (AED). L'AED permet non seulement de recenser les ports efficaces, mais aussi d'estimer le gain de production qui aurait pu être obtenu si tous les ports avaient employé leurs moyens de production (à savoir les infrastructures portuaires) de manière efficace. Cependant, l'AED est très sensible aux valeurs « atypiques », raison pour laquelle il est nécessaire de comparer des ports relativement homogènes.

Compte tenu de ces contraintes, les 49 ports de l'ASEAN inclus dans l'échantillon ont été regroupés en fonction de leur localisation géographique (port fluvial ou port maritime) et de leurs systèmes de manutention des conteneurs (portiques de stockage de conteneurs, chariots cavaliers et chariots élévateurs). Six catégories de port ont été créées, les ports pouvant appartenir à plus d'une catégorie. L'AED a été appliquée à ces différentes catégories. Dans celles-ci, le débit annuel de conteneurs en 2014 a été choisi comme extrant, tandis que les intrants incluent les variables suivantes: profondeur maximale au quai (m), taille du conteneur (m²), longueur des quais (m), nombre de grues portuaires, nombre de portiques de stockage sur pneus, nombre total de portiques de stockage (tous les types⁴), nombre de chariots élévateurs et nombre de camions. Ces indicateurs ont été collectés auprès de plusieurs sources, principalement les sites internet des autorités portuaires.

La première catégorie inclut 37 ports et prend en compte le nombre total de portiques de stockage ainsi que les systèmes de chariots cavaliers. Il a été constaté qu'en 2014, si ces ports avaient fonctionné efficacement selon les hypothèses REC⁵ ou REV⁶, ils auraient pu augmenter leur débit de conteneurs de 20,17% (7,7 millions d'EVP) ou de 10,83% (4,1 millions d'EVP), respectivement. La même analyse de la capacité optimale de manutention des conteneurs est également effectuée pour les cinq autres catégories, faisant apparaître à chaque fois un résultat similaire, à savoir l'existence d'un déficit de production.

⁴ Incluant les portiques de stockage sur pneus, les portiques de stockage de conteneurs sur rails et les chariots cavaliers

⁵ Rendements d'échelle constants

⁶ Rendements d'échelle variables

Plus précisément, les résultats montrent que les ports les plus efficaces sont Tan Cang-Cai Mep (Vietnam), West Port Klang (Malaisie), Tanjung Perak (Indonésie), Berlian Jasa (Indonésie), Penang Port (Malaisie), le Terminal international de conteneurs de Jakarta (Indonésie), TLT-HTL⁷ (Thaïlande), PAS⁸ (Cambodge) et le seul port fluvial Đình Vũ (Vietnam). Saigon Premier (Vietnam) est un autre port fluvial proche de la frontière de l'efficacité. Certains ports maritimes affichent des scores d'efficacité très élevés tels que le Terminal international de conteneurs de Manille MICT (Philippines), le North Port Klang (Indonésie), le Terminal Petikemas Surabaya (Indonésie), le Terminal de Koja (Indonésie) et Makassar (Indonésie). Il a également été constaté qu'un petit nombre de ports fonctionnent avec des rendements d'échelle décroissants (leur taille étant un obstacle à leur bon fonctionnement), comme les ports de Belawan (Malaisie), North Port Klang (Malaisie), Saigon New Port (Vietnam) et Hai Phong Port (Vietnam). Au niveau des pays, les résultats suggèrent que les ports indonésiens sont plus performants que les ports vietnamiens, ce qui n'est pas le cas lorsque nous comparons seulement les ports maritimes fluviaux. Les ports malaisiens sont très efficaces et obtiennent les meilleurs scores toutes catégories confondues. Dans l'ensemble, la plupart des ports fonctionnent avec des rendements d'échelle croissants, ce qui indique que leur inefficacité tient à leur faible capacité opérationnelle.

Le dernier chapitre examine le niveau de concurrence sur les routes maritimes. En effet, le transport maritime de lignes régulières est une industrie à forte intensité capitaliste. Cette industrie est caractérisée par de fortes barrières à l'entrée. De plus, les flux de conteneurs sont déséquilibrés d'une région à l'autre. Par exemple, en 2017, sur l'itinéraire transpacifique, l'on a enregistré 9,7 millions d'EVP de plus sur le trajet allant de l'Asie de l'est à l'Amérique du nord qu'en sens inverse. Ces déséquilibres ont poussé les compagnies maritimes à former des alliances, également appelées « conférences », ou à fusionner afin de réduire la présence de conteneurs vides sur leurs trajets et afin de maintenir des taux de fret relativement stables. En juin 2018, les dix plus grands opérateurs de porte-conteneurs possédaient plus de 81% de la flotte mondiale, alors qu'en 1997 leur capacité ne représentait que 48%.

Ce chapitre utilise pour ses analyses empiriques la même base de données sur les connectivités portuaires que celle du deuxième chapitre. Les variables de cette base (le nombre de

⁷ Thai Laemchabang Terminal Co., Ltd. et Hutchison Laemchabang Terminal Limited

⁸ Port Autonome de Sihanoukville

voyages et la taille moyenne des navires opérant entre les ports d'origine et de destination) sont complétées par les variables suivantes: le nombre d'opérateurs de porte-conteneurs, le nombre de navires, l'indice de connectivité bilatérale, la distance maritime et le nombre de navires par opérateur. Les résultats de l'analyse descriptive confirment l'existence d'un déséquilibre régional entre les ports d'origine et de destination, en particulier entre l'Asie et l'Europe, et entre l'Asie et l'Amérique. Les plus grands navires sont déployés sur ces routes en raison des longues distances à parcourir et du haut degré de connectivité portuaire, en particulier entre l'Europe et l'Asie. Ces routes sont aussi les plus concentrées. Les plus hauts niveaux de concurrence sont observés sur les routes intra-africaines où la distance moyenne entre les ports est la plus courte, la connectivité bilatérale est très basse et les plus petits navires opèrent en effectuant peu de voyages. Au niveau interrégional, les niveaux les plus élevés de concentration absolue du marché (mesurée par le nombre moyen de navires par porte-conteneurs entre le port d'origine et la destination) sont observés sur les routes reliant l'Asie de l'Est et l'Europe de l'Est, l'Asie du Sud-Est et l'Europe de l'Est, l'Europe du Sud et l'Asie de l'Ouest, l'Europe de l'Ouest et l'Asie du Sud-Est. Il est démontré aussi que la concurrence est généralement plus forte sur les routes reliant les régions les moins développées telles que l'Afrique du Nord et l'Asie de l'Est.

En appliquant une analyse en composante principale (APC), nous avons identifié deux composantes qui expliquent 70,4% de la variance totale. Il convient de souligner que l'APC a été menée sur un échantillon de 3054 routes. En effet, dans le but d'obtenir des résultats plus cohérents, seuls ont été pris en considération les trajets sur lesquels il existe des services réguliers. C'est ainsi que les itinéraires empruntés moins de 12 fois par an ont été retirés de l'échantillon, tout comme les liaisons maritimes intra-pays.

La première composante est liée à la taille du marché, à la fréquence des services et à la concurrence (nombre de navires, de voyages, d'opérateurs). La seconde composante englobe une forme de concentration (mesurée par le nombre de navires par opérateurs) positivement corrélée à la longueur de la route et à la taille des navires. Une analyse du partitionnement des données basée sur les résultats de l'APC permet d'identifier cinq groupes distincts. Le premier et le troisième groupe sont significativement différents des autres. Les routes maritimes dans ces deux groupes sont principalement intra-asiatiques et peuvent être caractérisées par un niveau élevé de concurrence, tandis que les autres groupes associent des routes maritimes entre l'Europe et l'Asie

pour lesquelles la concentration du marché est la plus élevée. Une analyse similaire d'un échantillon de 800 routes maritimes confirme que les routes à grandes distances sont en général plus concentrées (moins d'entreprises y déploient des grands navires) et propices à l'existence d'économies d'échelle croissantes.

En conclusion, et pour résumer, la présente thèse contribue à la littérature en analysant les caractéristiques de l'industrie du transport de conteneurs par le biais d'outils méthodologiques tels que le MS-VAR, l'analyse réseau, l'AED, l'APC et l'analyse du partitionnement. Les résultats permettent d'apporter des éléments de compréhension de la nature cyclique du commerce conteneurisé, de mieux anticiper les effets de certaines variables sur les taux de fret, d'identifier des ports efficaces et enfin, de visualiser le niveau de concurrence sur des routes maritimes spécifiques. De plus, l'analyse des réseaux de l'industrie du transport maritime en 2014 fournit des réponses quant à la hiérarchie et la connectivité des ports dans ces réseaux pondérés par le biais de différentes mesures de centralité. Peu d'études existent sur l'intégration maritime au sein de la communauté ASEAN+3 ainsi que sur l'intégration de la communauté de l'ASEAN dans les chaînes d'approvisionnement mondiales. En incluant dans l'échantillon un nombre important de ports de l'ASEAN, la présente thèse souligne l'importance de leur intra-connectivité et met en évidence les ports les plus importants. Enfin, une dernière contribution significative à la littérature est l'application de l'AED en classifiant les ports et les terminaux de conteneurs de l'ASEAN en fonction de leur localisation et de leurs technologies de stockage de conteneurs, ce qui permet de mieux comprendre l'efficacité des différents types de ports et de fournir des estimations plus précises sur la possibilité d'augmenter le débit des terminaux de conteneurs de l'ASEAN.

Executive Summary

Since the introduction of the first modern intermodal shipping containers by Malcom Purcell McLean in 1956, the amount of transported containerized cargo has increased exponentially. Containerization revolutionized international trade by allowing companies to safely and efficiently transport at the necessary time, in the necessary quantity of finalized and intermediate manufactured goods. Container ports are not only an important component for trade competitiveness at both country and regional levels, but they also play an important role in strengthening the intra-regional trade integration.

This dissertation aims to analyze the structure and the evolution of the Container Liner Shipping Industry by paying particular attention to the maritime integration of ASEAN member states. This study is motivated by four main research questions: What are the main determinants of container freight rates in, either, a steady state of growth of the industry or in a crisis state? How is the container shipping network organized at both the world and ASEAN levels, and what are the roles of the different ports in these networks? Which are the most efficient ports in ASEAN, and what is their optimal container handling capacity? What is the level of competition on different maritime routes? To address these questions, four chapters have been developed.

Chapter 1 is dedicated to the relationship between the bunker price, the development of containership fleet capacity, the Global Economic Activity, the Containership Earnings and the container freight rates. The motivation of this research is to understand the consequences of the subprime mortgage crisis on containerized trade, which marked the end of one of the most profitable market cycles for the industry. In 2009, containerized exports dropped by 11%. As a consequence, freight rates plummeted. Since then, shipping companies have been struggling to remain solvent and the Container Liner Shipping Industry has entered into a period of low growth.

Previous research indicates that, on average, an economic cycle in the container industry lasts 7.5 years, and freight rates have a positive impact on company revenues. However, literature on freight rates has almost exclusively focused on the cost of transporting various raw materials, and very few studies have used the VAR approach to analyze the relationship between key variables in the container industry. This chapter aims to fill in this gap by applying the Markov Switching Vector Autoregressive (MS-VAR) model in the context of containerized trade under

the assumption of the existence of two regimes. MS-VAR provides accurate estimates regarding the duration of each regime as well as the switching probabilities. Moreover, it can identify different business cycles occurring during the observed period. As a proxy variable for freight rates, the China Containerized Freight Index (CCFI) was used. The Impulse Response Functions of CCFI following one standard deviation shock of the equation of the other variables was also estimated. It pins down the consistent and efficient estimates of the reaction of CCFI to different factors according to the two states of the industry.

The findings of the research illustrate that the two regimes are very persistent. The switching probabilities of Regime 1 to Regime 2 and vice versa are very low, 18.5% and 17% respectively. Regime 1 is characterized by a low level of economic activity and a high level of volatility of freight rates, while the second regime can be defined as a regime of high and stable container freight rates. Between May 2003 and February 2017, three major business cycles were identified. The first one is characterized by a period of long and steady growth which lasted until August 2008. The subsequent cycle was a transitional one which lasted 6 years. The third cycle is characterized by very low freight rates, low earnings, and a substantial increase in the size of the world fleet. Actually, the Danish Maritime Forum and International Shipping Council defined the current state of containerized trade as the “New Normal”, with an international trade growth lower than the global economic growth. The impulse response function shows that the variable which has a profound negative impact on container freight rates is the growth of the world fleet. Its effect is more pronounced under the crisis regime. On the other hand, earnings in the shipping market and the crude oil price are only significant in the second regime and both have a positive impact on CCFI. The global economic activity has a minor effect on CCFI in the crisis regime. These findings confirm that overcapacity in the industry has a substantial negative effect on the freight rates. Contrary to our expectations, the bunker price seems to be significant only in the context of a steady growth regime.

Chapter 2 aims to analyze the container shipping network at port, country and regional levels. It also examines the level of maritime integration of ASEAN member states within the global supply chain. In addition, a case study comparing the flows of the values of the total exports and the flows of containership vessels within the ASEAN+3 community provides important insights into the structure of the trade and maritime integration within the community.

This research adds value to the literature by providing a comprehensive analysis of different types of networks at port and country levels using a sample of 6,410 maritime routes connecting 153 major ports around the world. The sample contains all of the major ports in the ASEAN+3 community. Five directed weighted networks were built and named the following: “Maritime Port Network”, “Maritime Country Network”, “ASEAN+3 Maritime Port Network”, “ASEAN+3 Maritime Country Network” and “ASEAN+3 Export Country Network”. In the first four networks, the links between each pair of ports/countries are weighted according to the number of trips multiplied by the average size of the vessels operating on the maritime route. In the last network, the weights of the edges relate to the total value of exported goods between countries. Different weighted centrality measures were computed in order to highlight the role of different ports and countries within the shipping network. In addition, a clustering algorithm was used to determine the tightly interconnected communities. It is expected that communities such as ASEAN will be identified as specific clusters.

Previous research has revealed that the container shipping network has a hub-and-spoke structure. It is dominated by large ports having direct connections with one another. Graph theory provides useful tools to determine the roles of different ports within regional and global shipping networks. Hence, centrality measures indicate how the hierarchy among ports and the importance of a particular port vary. For instance, a port with a high coefficient value of degree centrality has strong connections with many ports. A high betweenness score indicates a regional hub port which is an obligatory passage to reach other ports, while closeness centrality shows the possibility of a port to quickly reach the other ports in the network.

The findings of this chapter confirm the hub and spoke structure of the Global Maritime Network. Singapore, Hong Kong, Ningbo-Zhoushan, Shanghai and Shenzhen have been identified as being major hubs. Ports with relatively low Indegree and Outdegree centralities such as Port Said, Balboa, and Belawan have very high betweenness centralities which indicates their strategic geographical positions and connections with ports situated at the periphery of the global network. When we aggregate the data at the country level, the “Maritime Country Network” shows a similar pattern. The European states, as well as North and South America, form linked communities. China, the U.S., the Netherlands, and Japan are important bridges to link communities together.

The intra-maritime connectivity between ports situated in the ASEAN+3 countries is also a subject of this study. The Japanese ports and Hong Kong play the most important roles in terms of incoming and outgoing traffic. However, Shanghai and Singapore are found to have the highest betweenness scores which makes them important intermediate points connecting many ports in the network. Furthermore, based on modularity analysis, we found a community of ports made up exclusively by ASEAN member states except the Philippines. This finding reveals that ASEAN states might have a good intra-regional maritime connectivity. The comparative analysis between the flows of total exports and ports' interactions within ASEAN+3 shows that both networks have similar features and, indeed, the trade competitiveness is related to the position of a country within the shipping network.

Chapter 3 provides a comprehensive analysis of the container port efficiency in the ASEAN community. In containerized trade, size does matter. The incentives to realize increasing economies of scale have pushed shipping companies to build bigger and more efficient vessels. Since 1997, the maximum size of a containership has tripled. These trends have implications on the ports, which must constantly improve their efficiency and productivity in order to avoid major congestion and bottlenecks.

Most of the authors focused on port efficiency have applied the nonparametric benchmark method, Data Envelopment Analysis (DEA). DEA allows researchers to not only determine the most efficient ports, but also estimate by how much an inefficient port would have been able to increase its outputs if it had used its inputs in an efficient way. However, it should be highlighted that DEA is very sensitive to outliers and it is necessary to compare homogenous units (ports).

Given these constraints, the 49 ports in the sample were categorized according to their geographical location (inland or seaport) and their container yard handling systems (RTGC⁹, yard gantry system, straddle carriers or forklifts). In total we set up six categories of ports and terminals in ASEAN, with ports being able to belong to more than one category. A DEA output oriented methodology was applied to these data sets, where the annual container throughput in 2014 was chosen as an output while inputs included the following variables: maximum depth at berth (m), size of the container yard (m²), length of the quays (m), number of quay cranes, number of RTGC,

⁹ RTGC refers to Rubber-Tired Gantry Crane

number of yard cranes (MRGC¹⁰ + SC¹¹ + RTGC), number of forklifts and Number of trucks. These indicators were collected from multiple sources, mainly port authorities' websites.

The first category combines 37 ports with yard gantry and straddle carrier systems. It was found that in 2014, if these ports had operated efficiently under CRS¹² or VRS¹³ assumptions, they would have been able to increase their container throughput by 20.17% (7.7 million TEUs) or 10.83% (4.1 million TEUs) respectively. The same analysis regarding the optimal container handling capacity was also completed for the other five categories.

More precisely, our findings show that the most efficient ports are Tan Cang-Cai Mep (Vietnam), West Port Klang (Malaysia), Tanjung Perak (Indonesia), Berlian Jasa (Indonesia), Penang Port (Malaysia), JICT¹⁴ (Indonesia), TLT-HTL¹⁵ (Thailand), PAS¹⁶ (Cambodia), and the only efficient inland port of Đình Vũ (Vietnam). Saigon Premier (Vietnam) is another inland seaport close to the efficiency frontier. Some seaports have very high efficiency scores such as MICT¹⁷ (Philippines), North Port Klang (Indonesia), Terminal Petikemas Surabaya (Indonesia), Koja Terminal (Indonesia), and Makassar (Indonesia). It was also found that a few ports operate under decreasing returns to scale, their size being an obstacle to operating efficiently. Such ports are Belawan (Malaysia), North Port Klang (Malaysia), Saigon New Port (Vietnam), and Hai Phong Port (Vietnam). At the country level, results suggest that Indonesian ports perform better than the Vietnamese ports, which is not the case when we compare only inland seaports. Malaysian ports are strongly efficient since they obtain the best scores whatever the category. Overall, most of the ports operate under increasing returns to scale. Thus, the reason for the inefficiency of ASEAN container ports might be related to their low operational capacity.

Chapter 4 investigates the level of competition on maritime routes in the Container Liner Shipping Industry. Indeed, container shipping is an asset-intensive industry characterized by high barriers to entry. In addition, the imbalance of container flows across the region is a feature of the shipping market. In 2017, the imbalances between Eastbound and Westbound container flows on

¹⁰ RMGC refers to Rail Mounted Gantry Crane

¹¹ SC refers to Straddle Carrier

¹² CRS refers to Constant Returns to Scale

¹³ VRS refers to Variable Returns to Scale

¹⁴ JICA refers to Jakarta International Container Terminal

¹⁵ TLT-HTL refers to Thai Laemchabang Terminal Co., Ltd. and Hutchison Laemchabang Terminal Limited

¹⁶ PAS refers to « Port Autonome de Sihanoukville » or also known as Sihanoukville Autonomous Port

¹⁷ MICA refers to Manila International Container Terminal

Trans-Pacific, Asia-Europe, and Trans-Atlantic routes were 9.7, 7.9, and 1.6 million TEUs respectively. Therefore, shipping companies have been forming alliances, also known as Conferences, in order to reduce the presence of empty containers on the backhaul trips and to keep the freight rates relatively stable. As of June 2018, the ten largest operators owned more than 81% of the world container slot capacity, while in 1997 their capacity accounted for only 48% of the total.

The dataset used in Chapter 2 to analyze the connectivity of 153 ports around the world has also been used in this chapter. In addition to the number of trips and average size of vessels operating between the port of origin and the destination, the following variables have been included: number of operators, number of ships, Liner Shipping Bilateral Connectivity Index (LSBCI), sea distance, and number of ships per operator. The results of the descriptive analysis show, as expected, a regional misbalance between ports of origin and destination, particularly between Asia and Europe, and Asia and America. The biggest vessels are deployed on these routes because of the long distance and the high degree of port connectivity with other ports, especially between Europe and Asia. These routes are also the most concentrated. The highest levels of competition measured by these simple instruments are observed on the intra-African routes, which can be characterized as having the shortest distance between ports, the smallest vessels, the lowest number of trips, and the worst bilateral country connectivity. Regarding the origin and destination across regions, the highest levels of absolute concentration (e.g. average number of ships per container carrier operating between the port of origin and the destination) of the market belong to the routes connecting Eastern Asia and Eastern Europe, South-East Asia and Eastern Europe, Southern Europe and Western Asia, and Western Europe and South-East Asia. It was also found that competition is stiffer on the routes connecting predominately less developed regions such as Northern Africa and Eastern Asia.

By applying Principle Component Analysis (PCA) on our dataset, we have identified two components which explain 70.4% of the variance. It should be highlighted that PCA was conducted on a subset of 3,054 routes. In order to focus on routes with regular services, routes with less than 12 trips were removed from the sample. In addition, all intra-country maritime connections were excluded.

The first component relates to the market size, frequency of services, and competition (number of ships, trips, carriers) while the second illustrates a certain form of absolute concentration (e.g. ships per carrier) positively linked to the length of the route and the size of the ships. The PCA-based Cluster Analysis identifies five distinct clusters. The first and the third cluster are significantly different than the others. They mainly include intra-Asian routes and can be characterized by a high level of competition, while the other clusters are associated with maritime routes between Europe and Asia for which the absolute market concentration is the highest. A similar analysis of a subset of 800 maritime routes confirms that long distance routes are in general more concentrated in absolute terms (fewer companies operating larger vessels), exploiting the large economies of scale.

To conclude, the contribution to the literature of this dissertation is fivefold. Firstly, conventional research instruments such as MS-VAR, PCA and Cluster Analysis were applied in the context of the Container Liner Shipping Industry. By doing so, the research creates new understanding of the cyclical nature of the containerized trade, the effect on some key variables on freight rates, and the level of competition on specific routes. Secondly, by extending the prior work on Network Analysis in the shipping industry, the ports' hierarchy and connectivity in weighted networks with respect to different centrality measures is evaluated. Thirdly, there have been very few studies on the maritime integration within the ASEAN+3 community, as well as the integration of the ASEAN community within the global shipping network. By including in the sample an important number of ASEAN ports, this study outlines the level of their intra-connectivity and highlights the most important ports in the community. In addition, a comparative case study of the flows of containerships and exports within the ASEAN+3 community reveals the level of maritime and trade integration. The final significant contribution to the literature is the application of DEA by categorizing ASEAN container ports and terminals based on their localization and container yard equipment. This enables researchers to better understand the efficiency of different types of ports, and also provides more accurate estimates about the potential increase of container throughput of the ASEAN community

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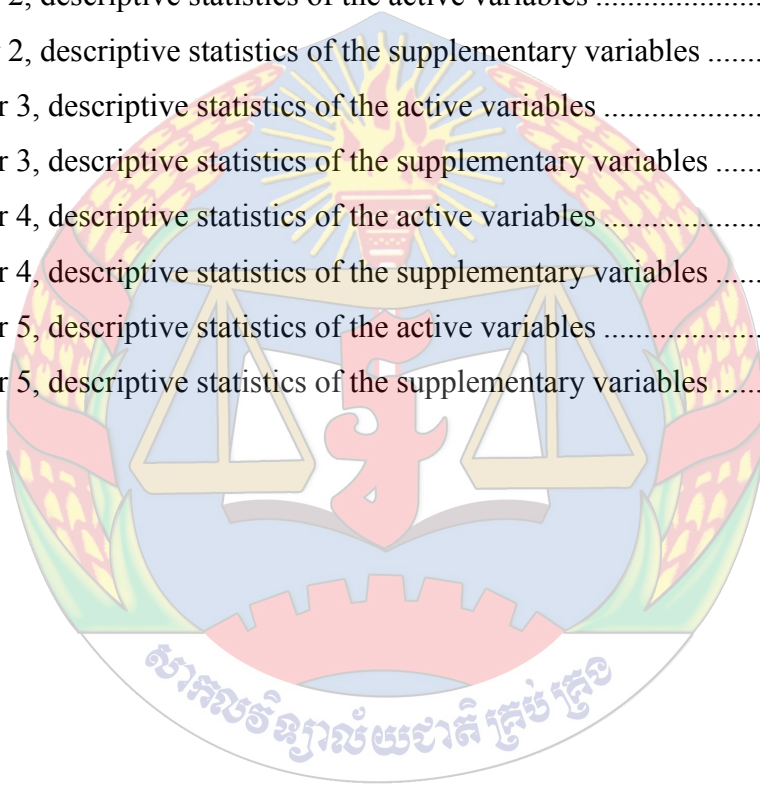
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Abbreviations



AEC	ASEAN Economic Community
AI	Artificial Intelligence
AIS	Automatic Identification System
ARDL	Autoregressive distributed lag
ASEAN	Association of Southeast Asian Nations
ASSM	ASEAN Single Shipping Market
BAF	Basic Ocean Freight
BDI	Baltic Dry Index
BIMCO	Baltic and International Maritime Council
CCFI	China Containerized Freight Index
CMA-CGM	Compagnie Maritime d'Affrètement - Compagnie Générale Maritime
CRS	Constant Returns to Scale
CY	Container Yard
DEA	Data Envelopment Analysis
DHC	Destination Handling Charge
DMU	Decision Making Unit
DRS	Decreasing Returns to Scale
DT	Decision Tree
ECSA	European Community Shipowners' Associations
EQUASIS	Electronic Quality Shipping Information System
ERS	Emergency Risk Surcharge
EU	European Union
EUR	Esposizione Universale Roma
FDI	Foreign Direct Investment
FE	Fixed Effects
FT	Forklift
GDP	Gross domestic product
GICA	Global Infrastructure Connectivity Alliance

GNP	Gross National Product
GREA	Global Real Economic Activity Index
GSM	Geographical Simulation Model
HHI	Herfindahl–Hirschman Index
HI	Homogeneity Index
HITS	Hyperlink-Induced Topic Search
HPI	Hymer–Pashigan Index
HT	Hausman–Taylor
IACS	International Association of Classification Societies
IAE	Institut d'Administration des Entreprises
ICASL	International Conference of Asian Shipping and Logistics
ICS	International Chamber of Shipping
ICT	Information and Communications Technology
ICT	International Container Terminal
IDT	Interactive Decision Tree
II	Instability Index
ILO	International Labour Organisation
IMO	International Maritime Organization
IRF	Impulse Response Function
IRS	Increasing Returns to Scale
ISO	International Organization for Standardization
JICA	Jakarta International Container Terminal
KDB	Korea Development Bank
LEMNA	Laboratoire d'Economie et de Management de Nantes-Atlantique
LFI	Long term composite Freight Index
LOADLINE	The International Convention on Load Lines
LSBCI	Liner Shipping Bilateral Connectivity Index
LSCI	Liner Shipping Connectivity Index
LSS	Low Sulphur Surcharge
MARPOL	The International Convention for the Prevention of Pollution from Ships

MICA	Manila International Container Terminal
MPAC	The Master Plan on ASEAN Connectivity
MPI	Malmquist productivity index
MSC	Mediterranean Shipping Company
MS-VAR	Markov Switching Vector Autoregressive
NGO	Non-governmental organization
OHC	Origin Terminal Handling Charge
PAS	Le Port Autonome de Sihanoukville
PCA	Principle Component Analysis
PPAP	Phnom Penh Autonomous Port
PSS	Peak Season Surcharge
RAM	Range Adjusted Measure
RE	Random Effects
RMGC	Rail Mounted Gantry Crane
RMIT	Royal Melbourne Institute of Technology
RTGC	Rubber-Tired Gantry Crane
SBF	Bunker Adjustment Factor
SC	Straddle Carrier
SE	Scale Efficiency
SEM	Structural Equation Modelling
SFA	Stochastic Frontier Analysis
SITC	Standard International Trade Classification
SOLAS	The International Convention for the Safety of Life at Sea
STS	Ship-to-Shore
TEU	Twenty-foot equivalent unit
THC	Terminal Handling Charges
TLT-HTL	Thai Laemchabang Terminal Co., Ltd. and Hutchison Laemchabang Terminal Limited
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
US	United States

Abbreviations

USD	United States Dollar
VAR	Vector autoregression
VAS	Value Added Services
VEC	Vector Error Correction
VRS	Variable Returns to Scale
WCO	World Customs Organization
WSC	World Shipping Council
WTI	West Texas Intermediate
WTO	World Trade Organization



Introduction



On August 31st 2016, the world's seventh largest shipping company, Hanjin Shipping Co. Ltd filed for court receivership¹⁸ after losing the support of its creditors, leaving its assets frozen. Banks led by state-run Korea Development Bank (KDB) found that the funding plan of the company was inadequate to tackle debt that stood at \$5 billion USD at the end of 2015¹⁹. It is by far the largest bankruptcy in the history of the shipping industry. As a consequence, ports from China to Spain denied access to Hanjin's vessels operating on 70 lines around the globe²⁰. Thousands of containers were stuck at ports, on ships or in inland container parks and this created a massive lack of containers in Asia. Carriers and shippers undertook emergency measures to fill in the void which caused turmoil in global freight rates and a major restructuring of the shipping market (Kuo et al., 2017). The failure of the biggest Korean shipping company shows that containerized trade is a dynamic sector in constant evolution.

For its 62 years of existence, the container shipping market has had many structural changes. The most recent one followed in the aftermath of the Subprime Mortgage Crisis when containerized trade decreased by 11% in 2009²¹. Due to the low demand, freight rates plummeted. The China (Export) Containerized Freight Index (CCFI) which serves as a barometer for the liner shipping industry decreased by 21.3%²². The crisis in the charter market was particularly severe, with the Containership Timecharter Rate Index falling by 62%²³. The Subprime crisis marked the end of one very long cycle spanning from 1995 to 2008 in which, according to Grammenos (2013), it was "the most profitable cycle in the shipping industry".

The Container Liner Shipping Industry has entered into a period of low growth due to some fundamental changes in the world economy. Rex et al. (2017) emphasized the expected lower level of growth of the international trade because of the regionalization of the world economy and the emergence of new trading blocs such as ASEAN. In the near future many products might be produced locally due to the rise of Protectionism, Brexit, America First Policy, or tariffs on steal

¹⁸ Receivership refers to a legal situation in which an enterprise is held by a receiver, a person "placed in the custodial responsibility for the property of others, including tangible and intangible assets and rights", especially in cases where a company cannot meet financial obligations or enters bankruptcy.

¹⁹ <https://www.reuters.com/article/us-hanjin-shipping-debt-idUSKCN11603N>

²⁰ <https://www.zerohedge.com/news/2016-08-31/global-supply-chains-paralyzed-after-worlds-7th-largest-container-shipper-files-bank>

²¹ Authors estimations based on the statistics of Clarkson research

²² Authors estimations based on the statistics of Clarkson research

²³ Authors estimations based on the statistics of Clarkson research

imposed by the U.S. (ICS, 2018, Alix Partners, 2018). Regionalization of the world economy could be further enhanced by robotization. Garment manufacturing and other labor intensive industries might be reshaped by new technologies, such as Artificial Intelligence (AI) and 3D printing. At the same time, new opportunities might favor international trade, such as new potentially faster and more direct routes through the Arctic connecting Asia with ports in Europe and eastern North America²⁴.

In this doctoral thesis, the evolution and the structure of the Container Liner Shipping Industry are analyzed by paying particular attention to the maritime integration of ASEAN member states. The factors behind the freight rates, the maritime connectivity, the ports' efficiencies and the competition on maritime routes are the central topics of this research. Methodological tools such as Markov-Switching Vector Autoregressive (MS-VAR) approach, Graph Theory, Data Envelopment Analysis (DEA) as well as Principle Component Analysis (PCA) and Cluster Analysis are used to reveal how the container market is organized at global and regional levels.

This introduction is divided into three sections. First, a brief history of containerized trade, as well as the most recent trends in the sector, are presented. Secondly, a literature review for each of the main topics of this dissertation is shown. Finally, the research questions, along with the structure of each of the four chapters as well as the data that was used in this dissertation, are depicted.

1 Overview of the Container Liner Shipping Industry

Maritime transport is the backbone of international trade. It is the cheapest and oldest mode of transport²⁵. Nowadays, over 90% of the world's exports are carried by sea²⁶. According to Vigarié (1979), containerized trade has been the driver of globalization and it has dramatically

²⁴ <https://www.nytimes.com/interactive/2017/05/03/science/earth/arctic-shipping.html>

²⁵ <http://www.yourarticlelibrary.com/geography/transportation/water-transport-kinds-advantages-and-disadvantages-of-water-transport/42133>

²⁶ <https://business.un.org/en/entities/13>

transformed the world economy and ports' infrastructure. Even though container transport is a relatively new industry, it has gone through a number of structural changes.

1.1. Brief history of containerization

The sharp increase in international trade began in the early 19th century following the Industrial Revolution in Great Britain. The Globalization Era began and soon engulfed the U.S. and the whole of Europe. It was mainly propelled by advances in two sectors: transportation and Information and Communications Technology (ICT) (Baldwin, 2011).

However, until the mid-20th century the world economy was to a large extent divided into regions. Several factors slowed down the pace of globalization. Krugman et al. (1995) emphasized the existence of legal barriers to trade as well as high levels of tariffs on industrial products imported into industrialized countries until the first half of the 20th century. Seaborne trade was strictly regulated by the state and dominated by Strong Longshoremen unions. According to Levinson (2016), 60% to 75% of the cost of transporting cargo accrued during the time a ship was at dock. Damage and theft of goods was frequent. A common joke in New York was that the dockers' salaries were "twenty dollars a day and all the Scotch you could carry home" (Bernhofen et al., 2016). As a result, ships on the Trans-Atlantic routes were spending half of their voyage time docked in port (Levinson, 2016). The solution to these technical inefficiencies came from an industry outsider in the form of an uninspiring "tin can".

The first intermodal shipping container was used by McLean Trucking Co. in 1956. Malcolm McLean was an American trucker and entrepreneur who converted a World War II tanker named "Ideal X" into the first ship able to carry containers. Soon after, McLean found the first company specialized in container shipping, "Pan-Atlantic Steamship Corporation".

In the beginning, containerized trade was limited due to a directional imbalance and the lack of adapted infrastructure for handling containers at port. One of the first studies on container handling efficiency was conducted by Foster Weldon from Hopkins University in Baltimore. His research for Pan-Atlantic Steamship Corporation concluded that "[...] 20 to 25 feet containers would be most efficient in the Hawaii trade [...]" (Weldon, 1958). Since then, operational

efficiency has been a central topic in the containership industry. Berth utilization, scheduling, time spent at berth, and handling costs have become important indicators for measuring port productivity.

As shown in Appendix 0.A, the sharp increase in the growth of world trade coincided with the genesis of the global container era which dates back to the mid-60s (Bernhofen et al., 2016). During that period, the first purpose-build container terminal appeared at Port of Elizabeth, New Jersey. The International Organization for Standardization (ISO) adopted international standards for the size of containers (10, 20, 30 and 40 feet) as well as for the twistlock²⁷. This allowed the containership industry to grow considerably and investors began to build uniform container handling equipment and containership vessels. The fact that standardized containers could be easily loaded onto trucks and trains around the world made the rise of so-called “intermodal transport” possible.

The logistical efficiency gained by using containers was demonstrated during the war in Vietnam. Following some suggestions from Malcolm Mclean in 1967, new terminals were built in Da Nang and Cam Ranh Bay, and after that the majority of military deliveries were transported in containers. A study showed that between 1965 and 1968, the U.S. army would have saved 882 million USD if it had adopted containerization earlier (Levinson, 2016).

In the beginning of the 70s, due to overcapacity, freight rates started to fall and the first major alliances, i.e. Trio Alliance²⁸, and mergers, i.e. Hapag-Lloyd²⁹, took place. The hub-and-spoke structure of containerized transport had already been well established by this period. The major Liner shipping companies maintained direct connections between major container ports. Mostly, smaller shipping companies offered services between a major hub port and small feeder ports.

Convinced by the gains in marginal efficiency that they were able to realize, shipping companies considerably increased the size of their ships. By the beginning of the 80s, some containerships had the slot capacity of 4,100 TEU. Therefore, loading and unloading such a huge

²⁷ A twistlock and corner casting together form a standardized rotating connector for securing shipping containers

²⁸ Trio Alliance operated on the Pacific maritime routes and it was formed by two British, two Japanese companies as well as the German Hapag-Lloyds.

²⁹ Hapag-Lloyd is a merger between the at the time two biggest shipping companies in Germany.

quantity of containers required a good connection with the hinterland. Massive infrastructure projects for new container terminals began, not only in Europe and the U.S. but also in Singapore, Hong Kong, Japan, Australia and China. Long-time established maritime transport centers such as Boston, Richmond, Gulfport, San Francisco, London, Liverpool and New York were replaced by new emerging maritime cities like Charleston, Savannah, Alameda, Oakland, Rotterdam and Felixstowe.

In the late 70s and 80s, a series of market liberalization reforms in the shipping, rail and truck sectors were adopted. It made it even cheaper to transport cargo in containers, which further increased demand. New companies started to enter the market. Mediterranean Shipping Company (MSC) emerged in 1970. In 1973, Maersk Line purchased its first containership, and eight years later the company became the 3rd largest container operator. CMA-CGM, the third largest company in 2018, was founded in 1978 under the name of CMA³⁰. As transporting intermediate and final products became cheaper, manufacturing companies in developed countries started to outsource some of their activities abroad in order to limit their production costs. A major concern for manufacturers was to accurately predict future demand for a specific product and to keep considerable inventory in place in order to satisfy potential increases. Thus, surplus and waste were major issues, and companies needed to have reliable and easily adjustable supplies.

Containerization and efficient supply management were key components of the so-called just-in-time system. This production process allows a company to deliver “only the necessary products at the necessary time in necessary quantity” (Sugimori et al., 1977). This concept was first applied by the Japanese automobile company Toyota. Since the 80s, we have observed a massive outsourcing of production in many industrialized countries in Europe and North America. In 2004, nonfarm inventories in the U.S. were 1 trillion USD lower than they would have been had they stayed at the 1980 level, relative to sales (Levinson, 2016).

Nowadays for instance, the parts of an ordinary iPhone are produced all over the globe. Audio chips are manufactured in China, South Korea, Taiwan, Japan and Singapore. The battery is produced by a South Korean company with manufacturing centers in 80 other countries. The camera could be produced in Australia, Brazil, China, India, Indonesia, Japan, South Korea or

³⁰ CMA refers to “Compagnie Générale Maritime”

more than a dozen other countries throughout Europe and Latin America. Finally, all these parts are shipped in containers to Shenzhen, China where the majority of the assembling is undertaken³¹. Logistics management and reliable and efficient supply systems has been made possible by the development of both the container transport and the ICT.

1.2. Current trends and structure of the containerized trade

In 2016, the volume of container trade represented 16.7% of the total seaborne trade and 23.8% of the loaded dry cargo³². Its value is estimated to be around 60%³³ of the world seaborne exports. The sector is essential for the global economy. As Mr. Jan Hoffman, Chief of Trade Logistics Branch, Division on Technology and Logistics, UNCTAD stated, “Without maritime transport and related developments in transport technologies, in particular containerization, globalization as we know it would not have materialized.”³⁴

Nowadays, the main container export region is the Far East. It accounts for 60.99% of the total exports (Figure 0.1). The shares of the developed regions, Europe and North America, are 19.03% and 8.50% respectively. The leading container exporter is China. It represents around 19.95% of the world containerized trade³⁵.

³¹ <https://www.lifewire.com/where-is-the-iphone-made-1999503>

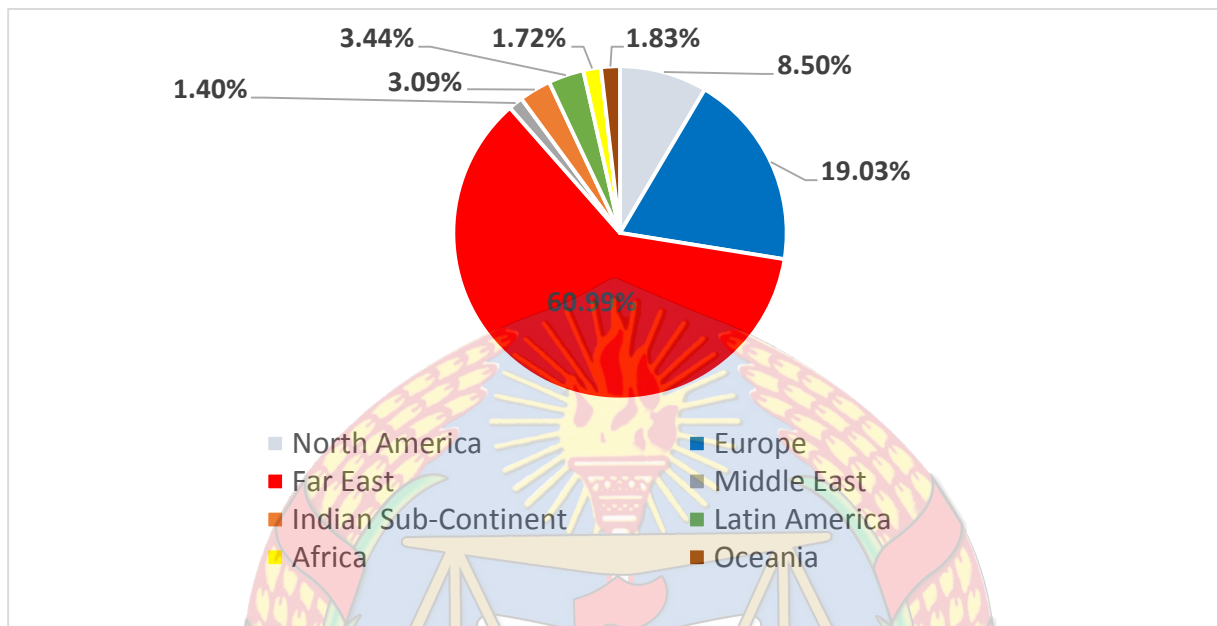
³² Author’s estimations based on the official statistics of UNCTAD and Clarkson Research

³³ <http://www.worldshipping.org/about-the-industry>

³⁴ <http://www.porteconomics.eu/2018/04/03/seaborne-trade-has-brought-prosperity-how-to-ensure-its-sustainability/>

³⁵ Author’s estimations based on the official statistics of Clarkson Research for year 2016

Figure 0.1: Share of the Container Exports per region in 2016



Source: Author's estimations based on the official statistics of Clarkson Research

There are three main inter-regional maritime routes. The first one is known as the Trans-Pacific, and it mainly connects Eastern Asia and North America. The second is between Europe and Eastern Asia (Asia – Europe), and the last links Europe and Northern America (Trans-Atlantic). Table 0.1 shows significant differences in the container trade flows between Eastbound and Westbound directions. On the Trans-Pacific and Asia-Europe routes these imbalances are the highest, with values of 9.7 million TEUs and 7.9 million TEUs respectively.

Table 0.1. Containerized trade on major East-West trade routes in million TEUs, 2014-2017

Year	Trans-Pacific		Asia - Europe		Trans-Atlantic	
	Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
	Eastern Asia - North America	North America - Eastern Asia	Northern Europe and Mediterranean - Eastern Asia	Eastern Asia - Northern Europe and Mediterranean	North America - Northern Europe and Mediterranean	Northern Europe and Mediterranean - North America
2014	15.8	7.4	6.8	15.2	2.8	3.9
2015	16.8	7.2	6.8	14.9	2.7	4.1
2016	17.7	7.7	7.1	15.3	2.7	4.3
2017	17.9	8.2	7.6	15.5	2.9	4.5

Source: UNCTAD secretariat calculations based on data from MDS Transmodal (2017)

On the backhaul trips companies are confronted with the presence of many empty containers. One way to limit costs for the shipping companies is to increase the number of intraregional and non-mainlane services. In 2017, the former increased by 6.1% and the latter by 4.3% (UNCTAD, 2017). Another way is by forming alliances in order to share slot-capacity and maintain relatively stable levels of freight rates. Nowadays, the global container trade (i.e. roughly 90% of container capacity on the three major trade routes) is controlled by Alliances. Hoffmann (1998) pointed out that the main incentives for shipping companies to form alliances are “the desire to reduce the unit cost (i.e., to achieve economies of scale) and to increase income (i.e. to gain greater market power)”.

In 1997, the largest ships operating on maritime routes had a capacity of around 6,000 TEUs, and the market share of the ten largest carriers was 48% of the slot capacity (Hoffmann, 1998). Now in 2018, vessels are able to carry 22,000 TEUs, and the ten largest operators have more than 81% of the world container slot capacity³⁶, and they also form alliances to optimize their operations (Table 0.2).

³⁶ <https://alphaliner.axsmarine.com/PublicTop100/>

Table 0.2. Alliances in the Container Shipping Industry

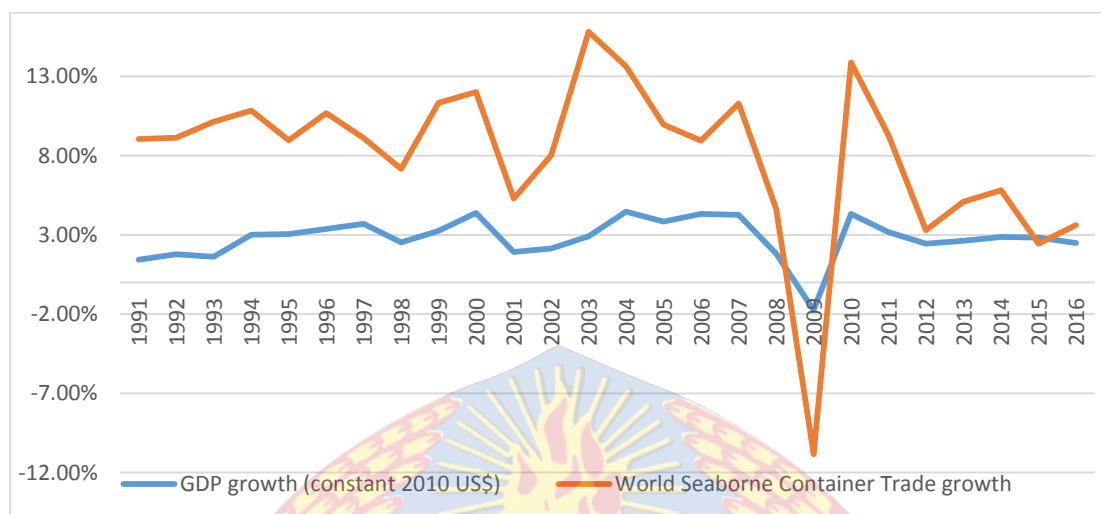
Alliance	Members	Share of the existing fleet capacity
2M	Maersk and MSC	33.4%
Ocean Alliance	CMA-CGM, Cosco, OOCL and Evergreen	28.7%
THE Alliance	Ocean Network Express, Hapag-Lloyd, and Yang Ming Line	17.1%
	TOTAL	79.2%

Sources: *Alphaliner Top 100, June 7th 2018*

Despite growing consolidation in the container trade in the last decade, freight rates have remained very low. The main carriers continue to invest in bigger and more efficient ships in order to minimize their operational costs. The main expectation is that this increase of the capacity will stop in the near future (Alix Partners, 2018, Rex et al., 2017). Shipping companies operate in an uncertain and changeable environment, and an important strategic decision is designing an optimal fleet of ships (Pantuso et al., 2014). Another main challenge is to predict the global demand for containerized cargo, which is related to the growth of the world economy.

Since the invention of the metal boxes, there has only been two times the growth of the container trade was lower than the growth of the real GDP (Figure 0.2). The first time was in 2009, following the crash of the world economy, and the second time was in 2015. Indeed the industry has since entered a period of slow growth. This new cycle, characterized by the world trade growth being lower than the global economic growth, has been named the “New Normal” by the Danish Maritime Forum (2016) and ICS (2018). Not surprisingly, the topic of The 10th International Conference of Asian Shipping and Logistics (ICASL 2017) was “Cooperation in Port Economy and Maritime Logistics under the ‘New Normal’”.

Figure 0.2. The growth of the volume of the world's Seaborne Container Trade and the real growth of the World GDP



Statistics collected from the World Bank and Clarkson Research

Container carriers have been struggling to remain solvent and to cover their operational costs. In 2008 the Clarkson Average Containership Earnings dropped by 13%. The next year they hit bottom by falling an additional 69%³⁷. These recent trends are having implications for maritime transport, and in particular, the seaborne trade in Eastern and South Eastern Asia. Thus, considering the ongoing regionalization of the world economy and the slowdown of Chinese exports, it is important to analyze the new emerging regions and Economic Blocks, i.e. the Association of Southeast Asian Nations (ASEAN).

1.3. Shipping Market and Regional Cooperation in ASEAN

With an average annual growth of more than 5% in the last decade, the ASEAN economy has become the 6th largest in the world and 3rd largest in Asia (ASEAN, 2016a). Indeed, ASEAN is on its way to creating a single market with a high degree of regional integration, which is not

³⁷ Authors' estimations based on the official statistics obtained from Clarkson Research

only limited to trade or financial issues (Nguyen et al., 2017b, Nguyen et al., 2016). Hence, the member states are committed to strengthening their maritime connectivity through the establishment of an ASEAN Single Shipping Market (ASSM). ASSM aims to foster a competitive and efficient inter-state shipping service by increasing the level of integration with the global shipping system as well as by increasing intra-ASEAN connectivity (ASEAN, 2010). Among the priorities of ASSM is the improvement of the capacity of the 47 designated ports in ASEAN. A major issue for the community is the identification of bottlenecks across key areas of the region's supply chains (ASEAN, 2016b). Therefore, it is necessary to conduct an analysis of the efficiency of the ASEAN ports by identifying the most productive ones as well as those having an important role in connecting ASEAN to global and regional shipping networks. The ASEAN Transport Strategic Plan states:

“Towards greater connectivity, efficiency, integration, safety and sustainability of ASEAN transport to strengthen ASEAN's competitiveness and foster regional inclusive growth and development (ASEAN, 2015b)”

ASEAN represents 13.47% of the World Container Throughput³⁸. There are two major maritime countries in the community, Singapore and Malaysia. According to the statistics of the World Bank, the former accounts for 33.54% of cargo passing through ASEAN ports while the latter is 26.01%. According to the Liner Shipping Connectivity Index (LSCI), the connectivity of the ASEAN community to global shipping networks has improved significantly in the last decade. From 2005 to 2016, LSCI increased by 65.06% with an average annual growth rate of 4.30%. However, disparities across ASEAN member states are considerable.

Throughout its six decades of existence, the container shipping industry has been driven by constant improvement of the (i) productive efficiency of ports (handling as many containers as possible by using the port's equipment and the infrastructure), (ii) marginal efficiency of carriers (transporting as many containers as possible in one ship and avoiding the presence of empties on the backhaul voyage) (iii) operational efficiency of ships (limiting the operational costs such as the bunker costs), network optimization of operators (efficiently distributing the cargo to the final destination and avoiding any disruption in the supply chain), time efficiency (lessening the

³⁸ Authors estimations based on the official statistics of the World Bank

delivery time from the origin to the destination) and (iv) the efficiency of intermodal transport connections (transporting the cargo directly to the customer by different means of transportation such as trucks, trains, barges, etc.).

2 Literature review and contribution of the present thesis

The central topics for this research are the cyclical nature of the container market, the factors behind freight rates, the ports' connectivity, the ports' efficiency and the level of competition on maritime routes. Before stating the main research questions and presenting the design of this research, a brief literature review on the main findings and methods that have been used for each of the topics is provided. The main gaps in the literature have been identified as well.

2.1. Freight rates and cycles in the Container Shipping Industry

The World Shipping Council (WSC) defines freight rates as “the charge made by a shipping line for the transportation of freight aboard one of its ships from one place to another”. According to the Maersk Line, the total price for shipment consists of four main components. The first one is called Basic Ocean Freight (BAF) and reflects the origin and destination of the cargo, as well as the type of cargo: dry bulk³⁹ or reefer bulk⁴⁰. The second component is the mandatory surcharges and the costs not covered by BAS. The most frequent mandatory surcharges are the following:

- Bunker Adjustment Factor (SBF) – it incorporates the fluctuations on a quarterly basis of bunker cost (oil used by vessels);

³⁹ Dry cargo commodities are usually retail, auto and electronics parts, paper, textile products, etc.

⁴⁰ Reefer bulk refers to commodities transported in refrigerated containers such as fresh produce such as fruits, vegetables, meats, grains, oats, etc.)

- Low Sulphur Surcharge (LSS) – it covers the expenses related to the use of low-sulphur fuel (maximum sulphur content of 0.1%) due to some environmental regulations⁴¹;
- Emergency Risk Surcharge (ERS) - it covers costs related to the crossing of dangerous regions, including those that are threatened by hazards, violence or piracy;
- Terminal Handling Charges (THC) – charges related to the cost of handling (loading and discharging) containers in the terminals. There are two types: Origin Terminal Handling Charge (OHC) and Destination Handling Charge (DHC);
- Peak Season Surcharge (PSS) – Fee applied during high volume periods on specific routes.

These mandatory surcharges are updated and transparent to the public, and Maersk line publishes them regularly on their website⁴². For instance, on 1st June 2018, between the ports of Doha and Rotterdam, the mandatory surcharges were as follows: OHC = 210 EUR, DHC = 650 QAR, ERS = 55 USD, SBF is inclusive, LSS = 30 USD and PSS = 0 USD.

In addition to the BAF and mandatory surcharges, there are also Value Added Services (VAS) which are related to specific requirements of the clients such as Container Cleaning, Garments on Hangers, Out of Gauge, Controlled Atmosphere, Cold Treatment, etc.

According to Maersk Line, BAS accounts for 50% of the total price of shipment, with mandatory surcharges accounting for 25%, and VAS for 25%. However, Gouvernal (2011) found that surcharges account for more than 50% in the total freight charged to customers.

Analyzing the freight rates is complex due to the existence of numerous parties involved in the shipment of the cargo. On the two ends of a shipment there are the consignor and the consignees, also known as the sender and the receiver. The consignor gives the cargo to the shipper who negotiates directly with a freight forwarder who is in charge of preparing and processing customs and other documentation, as well as performing activities related to international

⁴¹ From 2020, strict regulation in the seaborne trade will be imposed related to the amount of sulphur in the fuel.

⁴² <https://www.maerskline.com/news/2017/08/03/rates-and-pricing>

shipments. In addition, there is the shipping company who is the owner of the vessel, and who operates on particular regular routes (lines) on a fixed schedule. The company is represented by a shipping agent at a given port. In some cases, there is a consolidator who plays an intermediate role in selling cubic meters of container space to fill an unfilled container. The shipment is transported to the port of destination by a carrier and covered by an insurance company for any incidents that might occur during the transportation. Finally, banks are responsible for all financial aspects of the international shipment⁴³.

Often in the Liner shipping industry these rates are set by conferences and alliances (Hummels, 2007). Despite the monopolistic nature of the industry, freight rates have remained low due to overcapacity and the growth of the size of ships. An early study by Hummels (2007) concluded that freight rates are negatively affected when relatively small quantities shipped by smaller nations require vessels to stop in a number of ports in order to reach their optimal slot capacity. However, a recent report from UNCTAD (2017) shows otherwise. Actually, direct connections between ports has decreased while the number of trans-shipments has significantly increased. This suggests that the large ports are very interconnected. These findings have been questioned by ICS (2018). Pantuso et al. (2014) stated that the demand for maritime transportation reacts quickly to changes in freight rates.

Harley (1988) conducted a study on the Ocean Freight Rates and Productivity for the period 1740-1913. His study demonstrated that improvements in shipping, technological advances such as the adoption of metal hulls and steam propulsion played a crucial role in the decline of freight rates.

Different methods have been applied to investigate ocean freight rates. By applying seasonal unit root tests, Kavussanos and Alizadeh-M (2001) found that from 1978 to 1996 freight rates were not stochastically seasonal. The authors then applied a regression analysis by including a set of relative seasonal dummy variables. It was found that the bulk freight rates increased during early spring, i.e. March and April, and dropped sharply in June and July. These variations, however, differ across different sizes of ships (Capesize and Panamax) which suggests that companies have incentives to diversify their fleets. Different types of linear regression analyses

⁴³ <https://www.icontainers.com/us/2013/04/07/description-of-parties-involved-in-an-international-shipment/>

were applied by De Oliveira (2014), Tran and Haasis (2015), and Duru and Yoshida (2011). A major issue to overcome is the interdependence of the variable and the multicollinearity problem. Structural Equation Modelling (SEM) was used in the study of Lun et al. (2013). Main findings suggest that competition and fleet capacity have an important effect on freight rates. However, such methods do not allow us to investigate causality between the variables. To overcome these limits, some authors applied autoregressive methods. Such studies on the different freight rates in the dry bulk shipping market found a cointegration between freight rates and a causality of transitory nature (Veenstra, 1999, Veenstra and Franses, 1997)

Considering the cyclical pattern of the container industry discussed in (Grammenos, 2013), an appropriate method to investigate how freight rates are affected under different regimes, i.e. regime of crisis or regime of growth, is the Markov Switching Vector Autoregressive mode (MS-VAR). The autoregressive approach avoids the problem of over-identification and all variables are treated as endogenous. MS-VAR has been frequently applied in macroeconomic literature. Pioneer studies by Hamilton (1989) on the asymmetrical behaviour of the GNP in the U.S. in times of expansion and crisis, and by Engel and Hamilton (1990) on the USD exchange rate have shown the convenience of these models. In maritime economics, a similar methodology has been used by Bildirici et al. (2015) to investigate GDP growth in the U.S. and the Baltic Dry Index (BDI) by assuming the existence of three regimes. A complementary method to MS-VAR methodology is the estimation of Impulse Response Function (IRF). It describes the response of the observed variable to a one-time impulse in another variable in the model, while all other variables are kept constant (Hamilton, 1994).

Surprisingly, there are not any studies applying MS-VAR and IRF in the context of container shipping. Such analysis is necessary in order to better understand the relationship and causality between freight rates and other variables related to the industry.

2.2. Analysis of the Maritime Shipping Network

In recent years, maritime connectivity has become an important topic. The current unpredictable and changing environment, due to some industrial and global issues related to the

container trade and the world economy presented in Section 1.2. have forced carriers to focus on the optimization of their networks. In fact, UNCTAD (2017) included a sixth part to its annual report “Review on Maritime Transport” devoted exclusively to “Maritime Transport Connectivity”. This new section provides a comprehensive macro analysis on container ship deployment, liner shipping connectivity, intra-country connectivity, global shipping networks, transport facilitation and policy considerations. The report found that Alliances are currently focusing on faster transit time and improvement of the reliability of their services through the improvement of their network efficiency and by reducing port calls. Therefore, it is necessary to promote better linkages between domestic, regional and intercontinental shipping services.

An appropriate method for analyzing the maritime connectivity at a macro level is through the composite indicators. A number of indicators assessing the connectivity at a country level have been designed. UNCTAD computed the Liner Shipping Connectivity Index (LSCI)⁴⁴. “It covers 162 coastal countries and consists of five components, namely (a) the number of ships; (b) their container-carrying capacity; (c) the number of companies; (d) the number of services provided; and (e) the size of the largest vessels that provide services” (UNCTAD, 2010). An extension of this index is the Liner Shipping Bilateral Connectivity Index (LSBCI). LSBCI is based on five components capturing the overall quality of a liner shipping connection between two countries whether a direct liner service exists or not (Hoffmann et al., 2014).

In recent years, graph theory has been used to assess the connectivity of ports. The classical centrality measures proposed by Freeman (1978) have been used in the context of container trade by Ducruet (2013) and Wang and Cullinane (2016). This methodology allows us to identify the ports having the highest levels of connectivity (degree centrality), or those playing a role as intermediate passage between a pair of ports (betweenness centrality), or those able to quickly reach all other ports in the network (closeness centrality). Graph theory measures were used by Bartholdi et al. (2016) to create the Container Port Connectivity Index. The index includes the trade connectivity of ports within the network of container shipping where the weight of the links between ports is according to the values of LSCI. The importance of each port is estimated based on the direct connections of the port as well as the level of connectivity of its immediate neighbors. The authors used the Newman and Girvan (2004) approach to identify the importance of a port

⁴⁴ <https://data.worldbank.org/indicator/IS.SHP.GCNW.XQ?view=chart>

within its community as well the “HITS⁴⁵” algorithm of Kleinberg (1999). In the context of maritime trade, a port with a high HITS inbound score has significant power to aggregate goods, and a port with a high HITS outbound score has important influence to distribute them (Bartholdi et al., 2016).

Regional importance and intraregional port connectivity can also be analyzed through Graph Theory. According to Ducruet and Notteboom (2012), the betweenness coefficient measures the connectivity, while the betweenness score is an index of accessibility. Gastner and Ducruet (2015) analyzed the distribution of the ports’ degree centrality over the period from 1890 to 2008 by applying various probabilistic models. A recent study of Kang and Woo (2017) concluded that the liner shipping networks have the characteristics of free-scale networks and that the container throughput of a port is determined not only by macroeconomic variables and its service capacity, but also by its centrality measures. The graph theory was also used by Laxe et al. (2012) to assess the reaction of the industry to the financial and economic crisis by analyzing the containerized traffic from 2008 to 2010.

Despite the recent interest in the subject of maritime connectivity and ports’ centrality, there is a lack of research on the global shipping network where the connectivity of the ports is estimated based not only on the ship calls and the number of services, but also on the size of vessels operating on the maritime routes. In addition, there is a limited number of empirical analyses on the position of specific regions within the global network as well as the level of intra-regional integration. An interesting topic that has not yet been investigated is the similarity between the Maritime Connectivity (in terms of ports’ connections) and the “Trade Connectivity” (in terms of value of exported goods).

2.3. Container Ports’ efficiency

Since the invention of containers, port efficiency has been central to the trade competitiveness of a country’s economy. Following the containership upsizing of the last few years, a major challenge for ports has been to optimize their operations in order to quickly load

⁴⁵ Hyperlink-Induced Topic Search

and unload large vessels (Alix Partners, 2018, UNCTAD, 2017). Ports being efficient in their operations attracts higher volumes of cargo. Therefore, important investments have been made in order to modernize port infrastructure. From 1990 to 2017, the solely private participation in port infrastructural projects totalled around 84 trillion USD⁴⁶. According to the World Bank, the highest share was Latin America and the Caribbean region (25.8 trillion USD), followed by East Asia and the Pacific⁴⁷ (23 trillion USD), and South Asia⁴⁸ (12.4 trillion USD).

The first mathematical measure of efficiency related to resources utilization was established by Debreu (1951). Later, Farrell (1957) used an output-input based ratio, also known as the “Farrell efficiency”, to determine by how much a Decision Making Unit (DMU) was able to reduce its inputs and at the same time produce the same amount of output. This ratio was the basis for the benchmarking method “Data Envelopment Analysis”, which is a straightforward nonparametric method estimating the technical efficiency of a given DMU by attributing a score between 0 (inefficient) and 1 (efficient). Charnes et al. (1978) designed the so-called DEA-CCR model, which estimates the efficiency of each DMU regardless of its size (under the assumption of Constant Returns of Scale (CRS)). Banker et al. (1984) applied a model named DEA-BCC which allowed them to shift the benchmark frontier in order to compare only DMUs having a similar size (under the assumption of Variable Returns to Scale (VRS)). CRS efficiency scores represent the overall technical efficiency of a given DMU compared to the most efficient ones in the sample. Under the assumption of VRS, the “pure technical efficiency” is estimated by comparing a given DMU to its peers who have a similar size. By dividing the CRS score by the VRS score, one can get the ratio of Scale Efficiency (SE). In the context of port productivity, if SE is lower than one it means that the port operates under decreasing returns to scale and has not reached its optimum size, i.e. a future investments in infrastructure could be considered. When the SE score is greater than one, it means that the port experiences Decreasing Returns to Scale (DRS) and its size has a negative effect on its productivity, i.e. strategies to reduce the size of the container park or the terminal could be considered. If SE is equal to one, the observed port has the optimum size and operates under CRS.

⁴⁶ <https://ppi.worldbank.org/snapshots/sector/ports>

⁴⁷ list of countries in East Asia and Pacific is available here: <https://data.worldbank.org/region/east-asia-and-pacific>

⁴⁸ list of countries in South Asia is available here: <https://data.worldbank.org/region/south-asia>

Considering the homogenous nature of container ports (similar technology, i.e. quay cranes, gantry cranes, forklifts, etc.), DEA allows researchers not only to determine the most efficient ports, but also to estimate by how much an inefficient port would have been able to increase its outputs if it had used its inputs in an efficient way. A similar approach is Stochastic Frontier Analysis (SFA), introduced by Aigner et al. (1977). The approach was widely applied in the context of the evaluation of ports' productivity (Hai-bo and He-zhong, 2009, Cullinane et al., 2002). A suitable method of comparing the efficiencies of two DMUs or of a number of DMUs for a number of periods is the Malmquist productivity index (MPI) designed by (Caves et al., 1982). In the studies of Núñez-Sánchez and Coto-Millán (2012) and Wilmsmeier et al. (2013), MPI was used to assess the improvement of efficiency of container ports throughout a given period of time.

In most of the studies, the DEA approach was combined with another method in order to improve the reliability of the results. Cullinane et al. (2006) applied both DEA and SFA methods and found that the ports' efficiency scores under both methods were very similar. Fuzzy Theory-based DEA model was applied by Bray et al. (2014) to assess the efficiency measurement for transportation systems, considering uncertainty in the data. The network-DEA centralized efficiency model was applied by Wanke (2013) and showed that a private administration exerts a positive effect on physical infrastructure efficiency levels, while the hinterland size has a positive impact on shipment consolidation efficiency levels. The results of DEA analysis can also be compared to the results of classical Cluster analysis, as we can expect that the most efficient and inefficient ports would belong to different clusters (Sharma and Yu, 2009, Wu et al., 2010, Acer and Timor, 2017). It should be highlighted that DEA is sensitive to outliers, and thus it is necessary to compare similar ports (existence of RTGC, maximum size of vessels arriving at the port, geographical position, etc.) before concluding which are the most efficient ports in the sample.

There have not been any studies regarding the designated ports in the ASEAN Single Shipping Market. Considering the importance of the ports' infrastructure for regional competitiveness, additional studies on optimum container handling capacity of ASEAN ports as well as the assessment of their efficiency are necessary.

2.4. Competition on Maritime Routes

As we have seen in Section 1.2. , issues related to the growing consolidation of the liner shipping business should be addressed. Despite a series of mergers and acquisitions in the industry, freight rates have remained low due to the overcapacity. Rex et al. (2017) and UNCTAD (2017) expressed concerns about potential bankruptcies. Clark et al. (2004) demonstrated that a major problem faced by carriers is transporting empty containers on back-haul trips.

In order to assess the competition in a given market, Hymer and Pashigian (1962) built the so called Instability Index (II) which is mathematically expressed as:

$$II = \sum_{i=1}^n \left| \frac{a_{t,i}}{A_t} - \frac{a_{t-1,t}}{A_{t-1}} \right|$$

where n refers to the number of firms, A refers to the number of transported containers, t is the time period and a is the containers transported by firm i . If the II value is closer to zero, it means that the competition is relatively stable. Main limits are that the II value is sensitive to the size of the sample and small firms do not contribute significantly to the value of the index.

Another index which could be used to analyze the degree of competition is the Herfindahl–Hirschman Index (HHI) developed by two economists: Orris C. Herfindahl and Albert O. Hirschman. The index is useful for detecting monopolistic markets and is depicted by the formula:

$$HHI = \sum_{i=1}^N s_i^2, HHI \in [0; 1]$$

where s_i is the market share of firm i and N is the number of firms in the industry. A low value of HHI indicates a highly competitive market. While estimating the index, the geographical dimension and any other specifications of the market should be taken into account in order to improve accuracy in the analysis.

Other indices like the Gini coefficient, combined with the Lorenz curve, could be used to detect highly monopolistic markets. In addition, methods such as Principle Component Analysis

and Cluster Analysis could be applied to detect highly competitive market segments by including multiple variables.

In the context of the maritime industry, most of the research has been on the assessment of the level of consolidation of the container operators. Luo et al. (2014) used the HHI coefficient to investigate the factors behind growth in the both owned and charter fleet capacities of the shipping operators. Their results suggest that the capacity expansion rate of larger companies is lower than smaller ones. In addition, the market expansion of the previous year has a negative effect on market share growth of the small companies, while influencing positively the market share of the largest companies. Sys (2009) used a Lorenz curve to represent cumulative percentage of the total number of liner operators and the cumulative percentage of the fleet capacity (in TEUs). It shows that between 1999 and 2008 there were increasing trends of market concentration. In addition, the values of the HPI and HHI suggest a stable level of competition and a slightly monopolistic market, respectively.

Inter-port competition was the subject of De Oliveira and Cariou (2015) who applied a truncated regression with a parametric bootstrapping model for 200 container ports in 2007 and 2010. The following variables were included in their model: the population of port-city, the level of connectivity of the country where the port is located, the Herfindhal–Hirschman index (HHI) of traffic of ports, and the market share of a port. Their results show that port efficiency decreases with competition intensity when measured in a range of 400–800 km (regional level); and the effect from competition is not significant when competition is measured at a local (less than 300 km) or at a global (more than 800 km) level.

Most studies focus on the competition between container carriers. Often, the market concentration has been estimated based on the existing charter and owned slot capacity (in TEUs), regardless of the operations on specific routes. Some studies provide some measures of competition on the main inter-regional routes (Trans-Pacific; Asia-Europe; Trans-Atlantic). However, more research is needed to evaluate the level of competition on intra-regional routes, especially in regions like South East Asia and Africa.

3 Research design, questions, methods and data

The Container Shipping Industry is facing uncertainty and a number of challenges under the “New Normal”. Low and volatile freight rates are a primary concern for container operators. Thus, it is necessary to determine the main factors behind the freight rates and how the freight rates react to some external shocks of other key variables in the industry, such as fleet development, bunker price, brokers’ earnings or the world’s economic activity. The oversupply in the container segment implies that major ports should be able to efficiently accommodate larger ships in order to remain competitive. In addition, port efficiency is an important component of the trade competitiveness at a country and regional level. Emerging regions like ASEAN focus on the development of their ports’ infrastructure in order to improve their integration into the global supply chain and boost intra-regional trade. In order to overcome the problem of imbalanced flows of containers, container operators undertake strategies to maximize their costs by optimizing their shipping networks, while policy makers seek to identify the most crucial ports for the stability of the whole container shipping network. Furthermore, the ongoing consolidation in the shipping market has made it crucial to analyze the level of competition on different maritime routes. These topics require the employment of different methods in order to better understand the structure of the Container Liner Shipping Industry at global and regional levels.

3.1. Research design and questions

This PhD dissertation is divided into four chapters and each one has the structure of a standard scientific article. The main topics that have been developed are related to container freight rates, maritime network and port connectivity, port efficiency, and level of competition on maritime routes.

Chapter 1 is devoted to the macro factors behind the freight rates. Considering the volatile nature and cyclical patterns of the container prices, the following questions have been addressed: What is the relationship between the bunker price, the development of containership fleet capacity, the Global Economic Activity, the containership earnings and the freight rates? How do oil prices,

fleet developments, economic activities, and container shipping earnings affect the freight rates in times of growth and crisis? What are the main characteristics of the identified market cycles, which have occurred in the last 13 years?

To respond to these questions, a brief analysis of the current trends in containerized trade as well as a definition of the freight rates and their components is provided. Secondly, a summary of the outcomes of some empirical studies related to freight rates in the bulk and container segments is presented. Based on the literature review, it was found that the Markov Switching Vector Autoregressive (MS-VAR) approach is an appropriate way to investigate the factors behind the freight rates. This method is presented in the third section. MS-VAR is a combination of the VAR model and the Markov chain process. The former allows us to treat all variables as endogenous and to avoid the problems of over-identification, while the latter takes into account the probability of switching from one state of the market to another. MS-VAR can be combined with the Impulse Response Function (IPF) which allows for the investigation of how fundamental disturbances affect the variables in the model under each of the identified regimes. The outcomes of the study are summarized in the fourth section. It includes a descriptive analysis of the variables in the MS-VAR model along with the estimated Smoothed probability coefficients for the two regimes. In addition, three major business cycles have been identified based on the switching probabilities. The impulse response functions show how CCFI⁴⁹ reacts to shocks of one standard deviation of the residuals of each equation (Crude Oil, Earnings, Fleet or Global Activity) and are also presented. Finally, a discussion of the outcomes of the study is shown.

Chapter 2 investigates the characteristics of the shipping network and port connectivity by paying particular attention to the maritime integration within the ASEAN community. It aims to provide comprehensive analysis of the maritime connectivity at port, country, regional and global levels by addressing the following questions: What are the characteristics of the global maritime shipping network? What are the key ports in the network and what is their main purpose (transshipment port, gateway port, regional port, etc.)? What is the position of the ASEAN community in the global shipping network? How are the regional maritime connectivity networks

⁴⁹ China Containerized Freight Index

at port and country levels organized within the ASEAN+3⁵⁰ community? Are there any fundamental differences between maritime connectivity and countries' exports of all goods?

The introduction section of Chapter 2 discusses the structure of the shipping network as well as the ongoing maritime integration within the ASEAN+3 community. The literature review contains three parts. The first one presents the application of Graph Theory in the context of maritime transport. In the second part, some studies related to the analysis of maritime and trade networks within the ASEAN+3 community are highlighted. The added value to the study is emphasized at the end of the literature review. In order to analyze the different networks, the Graph Theory approach was used. It is presented in the third section. Ports or countries are treated as individual nodes and the interactions between them are actually the links (edges) within the network. The links between each pair of nodes (ports or countries) are weighted based on the number of trips multiplied by the average size of the vessels operating between each pair of nodes (port of origin and port of arrival). Then, weighted centrality measures such as degree, betweenness, closeness and hub coefficient are estimated. Detailed descriptions of the different networks at port and country levels, as well as the algorithms used and the modularity approach used to distinguish different clusters within the network, are also described. The Results section discusses the centrality measures at port and country levels, and shows the nodes which have the highest connectivity, play intermediate roles between different communities, have direct connections with most of the other nodes, or play the role of hub in a network. Since we have most of the major ports within the ASEAN+3 community, we can compare their maritime network (connections between ports) with their Export Network (value of flows of exports of all goods between countries) in order to see whether the maritime integration within ASEAN+3 has the same pattern as their Trade Integration. The conclusion summarizes the main findings and emphasizes some potential topics for future research.

Chapter 3 focuses on the port efficiency within ASEAN. Efficiency has been a central topic in the industry since the invention of containers. Country and regional competitiveness depends to a large extent on the efficiency of container ports. Indeed, the role of the ASEAN ports' productivity is a central topic for the implementation of the ASEAN Single Shipping Market

⁵⁰ The ASEAN Plus Three cooperation process began in December 1997 with the convening of an Informal Summit among the Leaders of ASEAN and China, Japan and the Republic of Korea.

(ASSM). Therefore, this chapter addresses the following questions: Which are the most efficient ports and container terminals in ASEAN? What is the optimum handling capacity for ASEAN container ports? What are the most efficient ports with respect to their type (inland or seaport) and their container handling equipment in the container park (RTG⁵¹, RMG⁵², Straddle carrier or forklift)?

To address these questions the third chapter of this dissertation is divided into nine sections. First, an introduction dedicated to the implementation of ASSM and the definition of port efficiency is presented. Secondly, a literature review on the main findings of the studies related to port efficiency is depicted. It includes methods, sample sizes and variables that have been used to assess port efficiency. It was found that the nonparametric benchmark method Data Envelopment Analysis (DEA) was widely used in the context of container port efficiency, and it is a suitable approach to evaluate the container ports in ASEAN. DEA allows us to determine the most efficient ports with respect to a set of inputs and outputs. In addition to the classical models under the assumption of Variable Returns to Scale and Constant returns to Scale, the super efficiency DEA scores could also be estimated in order to rank the efficient ports that we have identified. These different variations of DEA methodology are depicted in the third section. The data that have been used in the study are presented in the fourth section. The results for each category are described in the fifth section. In order to double check the DEA outcomes, PCA and Cluster analysis on the basis of simple productivity ratios, the Annual Container Throughput divided by the input variables (max depth at berth, Size of the container yard, length of the quays, number of quay cranes, number of yard cranes (MRGC, SC or RTGC), number of forklifts and number of trucks) were applied in the case of the first category of ports. It is expected that ports identified as efficient by the DEA method form separate clusters. Finally, a discussion on the main findings, policy recommendations, limitations and future research is provided.

Chapter 4 focuses on the competition on the maritime routes. Relevant questions that have been addressed are the following: What is the degree of competition on the different maritime routes? How does sea distance, bilateral countries connectivity and regional trade direction influence the level of competition between liner shipping carriers? How can the different maritime

⁵¹ RTG refers to Rubber Tyred Gantry crane

⁵² RMG refers to Rail Mounted Gantry crane

routes be classified in terms of competition, and to what extent do the geographical locations of ports matter in this typology of routes?

The last chapter of this dissertation is divided into four parts. First, the main concepts of competition and some market consolidation trends in containerized trade are presented. Secondly, a literature review of the studies analyzing the level of competition is provided. It was found that many researchers use classical concentration indices such as HHI,⁵³ HPI⁵⁴ and Gini coefficient in the context of competition in the shipping sector. Considering the dataset used for the study, it was possible to assess the level of competition on routes connecting individual ports only in absolute terms by taking into account the average number of carriers as well as the average number of ships per carrier operating between a given port of origin and destination. Additional variables regarding sea distance, bilateral country connectivity, number of trips and number of ships were also included in the study. A suitable method to reduce the dimensionality of the data is the Principle Component Analysis. Then, based on the identified components, a Cluster Analysis is conducted to categorize the ports with respect to competition. The findings of the study are presented in the third part of the chapter. It includes the analysis of the components, as well as a detailed description of the identified clusters of maritime routes. Finally, a discussion of the study's outcomes is included.

The Conclusion summarizes the main findings of this dissertation. A set of policy recommendations for global, regional and country levels are highlighted. Potential topics for future research and complementary methods to be used in the context of Container Liner Shipping Industry are also outlined.

3.2. Data used in the study

In this thesis, data from various sources was used. Appendix 0.B shows the main organizations providing data and market analyses in the Container Shipping industry. Organizations such as UNCTAD and the World Bank have a lot of available statistics, mainly at

⁵³ Herfindahl-Hirschman index

⁵⁴ Hymer–Pashigan Index

the country level. Consulting companies, such as Clarkson Research, Lloyds, Alphaliner and Drewry, provide a number of macro and micro data as well as weekly, monthly and yearly reports regarding shipbuilding, financial data, the containership fleet and other indicators. Upon request these companies are able to deliver micro data regarding ship traffic, market share on different maritime routes per operator, and other market insights.

Appendix 0.C. depicts all variables along with their sources for the empirical analyses in this dissertation. Indicators were collected mainly from Clarkson Research. The Shipping Intelligence Network⁵⁵ was used to determine the factors behind the freight rates. Access to this data is not free of charge. It requires an annual subscription. An index representing the global activity computed by Kilian (2009) was also used in this dissertation.

Port connectivity and maritime networks were investigated by using a dataset containing 6,410 maritime connections between 153 ports in year 2014 from “Lloyds List – Maritime Intelligence”. For each pair of ports the following variables are available: number of trips, number of ships, number of container carriers and average size of containership. This dataset could be used to determine the most important ports in the network based on different centrality measures and can identify clusters of interconnected nodes.

A major contribution of this research is the creation of a unique database containing information about the annual throughput and infrastructure specifications of the ASEAN container ports and terminals. It contains information from multiple sources, mainly ports’ official websites and studies from other researchers. This dataset is available in Appendix 3.A. Despite the growing number of studies on this matter, it is hard to find reliable and up-to-date information about port facilities and port annual throughput. This dataset is used to investigate the efficiency of ASEAN ports.

In order to analyze the competition on maritime routes, the Lloyds dataset was supplemented with indicators relating to the sea distance between ports estimated by Bertoli et al. (2016) and the Bilateral Liner Shipping Connectivity Index developed by Fugazza and Hoffmann (2016). These additional variables allow us to take into account more factors when analyzing the level of competition on the maritime routes.

⁵⁵ <https://sin.clarksons.net/>

The fact that some analyses in the current research are based on datasets built by the Author or purchased upon request from a company contributes significantly to the original and innovative character of this doctoral dissertation.



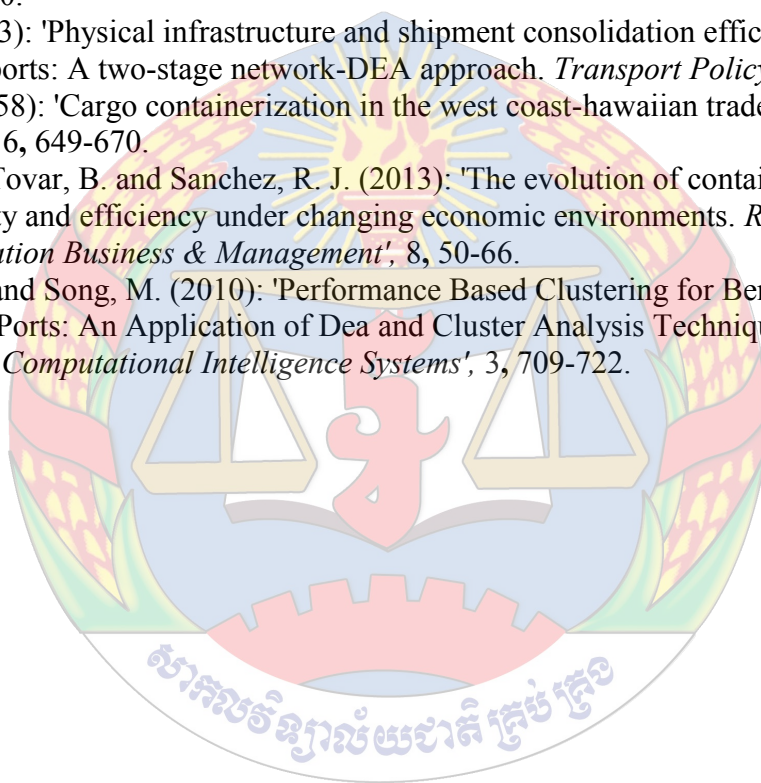
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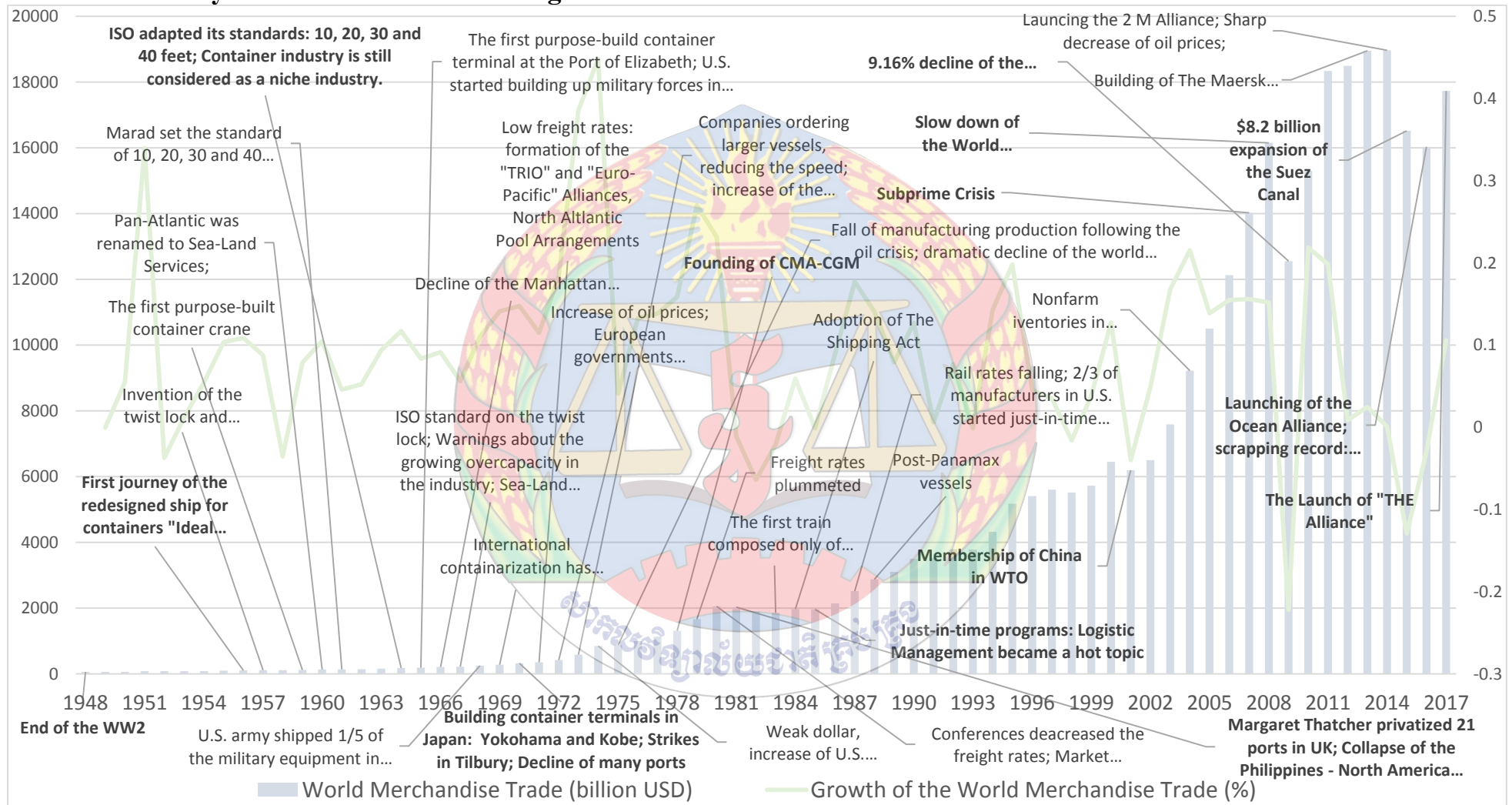
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5 Appendices

0.A. History of the containerization at glance



Data collected from UNCTAD

0.B. Main data providers and stakeholders in the Liner Container Shipping Industry

Organization	Status	Description	Data, Information and services	Website
Alix Partners	Consulting Company	Works includes enterprise improvement consulting, financial advisory services, information management services, and executing turnarounds of distressed and healthy companies.	Market insights and annual reports about the shipping market and port infrastructure	https://www.alixpartners.com
Baltic and International Maritime Council (BIMCO)	Association	BIMCO represents ship-owners. Its membership controls around 65 percent of the world's tonnage and it has members in more than 120 countries. The association's main objective is to protect its global membership through the provision of information and advice, and while promoting fair business practices, facilitate harmonization and standardization of commercial shipping practices and contracts.	Market insights and reports about the shipping industry	https://www.bimco.org
Clarkson PLC	Consulting Company	A leading provider of integrated shipping services related to broking, financial, support and research. Clarkson Research Services focuses primarily on the collection, validation, analysis and management of data about the merchant shipping and offshore markets	Data on shipbuilding, scrapping, ordering, revenues, freight rates, commodities trade and others	https://www.clarksons.com/
Danish Maritime Forum	Non-profit organization	It aims to bring together many stakeholders from across the industry with the objective to find new solutions to the most important challenges facing the industry. A major event organized by the organization is "Danish Maritime Days"	Market insights highlighting some of the major multi-stakeholders initiatives in the shipping Industry	http://www.danishmaritimedays.com
Danish Ship Finance	Financial Institution	Its business involves the provision of loans for shipping companies with all loans being secured by a ship mortgage. The company primarily finances its operations through the issuance of bonds on the Copenhagen Stock Exchange. It is a ship finance institute supervised by the Danish Financial Supervisory Authority.	Annual Report about the Shipping Market: "Shipping market review"; Industry's insights	http://www.shipfinance.dk/

Drewry	Consulting Company	It provides services through: Maritime Research, Maritime Advisors, Supply Chain Advisors and Maritime Financial Research. These divisions, combined, support the operational and strategic needs of an elite and diverse client base of maritime and shipping industry stakeholders.	Statistics, market insights and reports	https://www.drewry.co.uk/
Electronic Quality Shipping Information System (EQUASIS)	Non-profit organization	It is an information system which collates existing safety-related information on ships from both public and private sources, and makes it available on the Internet. It is a tool aimed at reducing substandard shipping, and it should be limited to safety-related information on ships. Equasis is a tool used for better selection of ships, but it is used on a voluntary basis and there are no legal pressure for industry to use it.	Statistics about the world fleet by type and class	http://www.equasis.org
Enterprise Surveys - the World Bank	International Organization	An Enterprise Survey is a firm-level survey of a representative sample of an economy's private sector. The surveys cover a broad range of business environment topics including access to finance, corruption, infrastructure, crime, competition, and performance measures. Some topics related to transportation of goods are covered as well.	Micro data on the business environment in different countries including Cambodia.	http://www.enterprisesurveys.org/
Global Infrastructure Connectivity Alliance (GICA)	International Organization	It helps policymakers and practitioners understand and leverage the megatrends and game changers that will shape global infrastructure connectivity. The organization aims to respond to the following trends: changing consumer patterns, rebalancing in Global Networks, deepened focus on Sustainability and Climate Change and Digital and Technological Revolution.	Market insights, resources and important links	https://www.gica.global/

International Association of Classification Societies (IACS)	NGO	It is a technically based organization that currently consists of twelve member marine classification societies. More than 90% of the world's cargo-carrying ships' tonnage is covered by the classification standards set by member societies of IACS. It also plays a role within the IMO, for which IACS provides technical support and guidance and develops unified interpretations of the international statutory regulations developed by the member states of the IMO. Once adopted, these interpretations are applied by each IACS member society, when certifying compliance with the statutory regulations on behalf of authorizing flag states.	The current resolutions and recommendations of IMO and their implementation status; Data on ships per class and per type.	http://www.iacs.org.uk/
International Chamber of Shipping (ICS)	Association	It is the principal global trade association for ship-owners, concerned with all regulatory, operational and legal issues, as well as employment affairs. The membership of ICS comprises national ship-owners associations representing all sectors and trades from 37 countries, covering more than 80% of the world merchant fleet.	Market Insights, Annual Review of the Shipping Market; Highlights the key issues in the industry;	http://www.ics-shipping.org/
International Maritime Organization (IMO)	International Organization	IMO is the UN specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships. IMO measures cover all aspects of international shipping – including ship design, construction, equipment, manning, operation and disposal – to ensure that this vital sector for remains safe, environmentally sound, energy efficient and secure.	Publications regarding the shipping market	http://www.imo.org
International Transport Forum	International Organization	It is an intergovernmental organisation under OECD with 54 member countries. It acts as a strategic think-tank, with the objective of helping shape the transport policy agenda on a global level and ensuring that it contributes to economic growth, environmental protection, social inclusion and the	Market insights, statistics and case studies related to the shipping industry.	https://www.itf-oecd.org/

		preservation of human life and well-being.		
Lloyd's List Intelligence	Consulting Company	The company provides a range of support services such as in-depth consultancy, investigations, due diligence, market trend analysis and credit risk appraisal for entire portfolios. Information is sought from a multitude of sources and incorporates some of the most extensive resources available including the world's largest AIS (Automatic Identification System) network, the largest online maritime database and the largest databank of marine / energy / commodity company credit reports.	An interactive online service offering detailed vessel movements, real-time AIS positioning, comprehensive information on ships, companies, ports and casualties as well as credit reports, industry data and analysis including short-term market outlook reports	www.lloydslistintelligence.com
MDS Transmodal	Consulting Company	It provides analyses on strategic, commercial and economic issues mainly related to freight transport and logistics. Its work is based on the development and maintenance of a unique and comprehensive set of databases and transport models as well as the expertise of our consultants.	Market Insights: "Container Shipping Bulletin" and data	http://www.mdst.co.uk/
Pricewaterhouse Coopers (PwC)	Consulting Company	It is a multinational professional services network headquartered in London, United Kingdom. It is the second largest professional services firm in the world, and is one of the Big Four auditors.	Company provides reports and market insights about the Transportation and Logistics sectors	https://www.pwc.com
The European Community Shipowners' Associations (ECSA)	Association	It is a trade association representing the national shipowners' associations of the EU and Norway. It controls 40% of the global commercial fleet, contributes 140 billion to the EU GDP and provides 2.1 million Europeans with careers both onboard and ashore.	Market insights and reports about the shipping regarding Trade policy, Social affairs,	http://www.ecsa.eu/

			safety and environment	
The Global Maritime Forum	Non-profit organization	It aims to promoting the potential of the global maritime industry. It convenes leaders from across the maritime community with policy-makers, experts, NGOs and other decision-makers and opinion shapers to discuss collective challenges and to work together on developing new solutions and recommendations.	Market insights, highlighting some of the major multi-stakeholders initiatives in the shipping Industry.	https://www.globalmaritimeforum.org/news
Trading across Borders - Doing Business, Measuring Business Regulations - The World Bank	International Organization	Doing Business records the time and cost associated with the logistical process of exporting and importing goods. Doing Business measures the time and cost (excluding tariffs) associated with three sets of procedures—documentary compliance, border compliance and domestic transport—within the overall process of exporting or importing a shipment of goods.	Time series data at a country level on time and cost regarding the trade across borders. There are other topics as well.	http://www.doingbusiness.org/data/exploretopics/trading-across-borders
United Nations Conference on Trade and Development (UNCTAD)	International Organization	UNCTAD works at the national, regional, and global level to address macro-level development challenges; achieve beneficial integration into the international trading system; diversify economies to make them less dependent on commodities; limit their exposure to financial volatility and debt; attract investment and make it more development friendly; increase access to digital technologies; promote entrepreneurship and innovation; help local firms move up value chains speed up the flow of goods across borders; protect consumers from abuse; curb regulations that stifle competition; adapt to climate change and use natural resources more effectively.	Time series regarding the merchant fleet, the trade of goods, country's throughput; Reports and studies about the shipping market	http://unctad.org/
World Bank Open Data - the World Bank	International Organization	IT provides a listing of available data, pre-formatted tables, reports and other sources for various topics.	Macro data at country level available, market insights, reports and other useful sources	https://data.worldbank.org/

World Customs Organization (WCO)	International Organization	It is an independent intergovernmental organization whose primary mission is to enhance the effectiveness and efficiency of Customs administrations worldwide. As the only intergovernmental organization specialized in Customs matters and currently represents 182 Members. WCO provides a forum for Customs administrations and their stakeholders to hold discussions, exchange experiences, and share best practices on a range of international Customs and trade issues.	Information regarding customs procedures and regulations	http://www.wcoomd.org/
World Shipping Council (WSC)	Association	World Shipping Council members operate approximately 90 percent of the global liner ship capacity, providing approximately 400 regularly scheduled services linking the continents of the world. Collectively, these services transport about 60 percent of the value of global seaborne trade, and more than US\$ 4 trillion worth of goods annually.	Market insights, issues in the industry and information	http://www.worldshipping.org/
World Trade Organization (WTO)	International Organization	WTO assists its members on a daily basis to that negotiations progress smoothly, and that the rules of international trade are correctly applied and enforced. The WTO agreements cover goods, services and intellectual property. They spell out the principles of liberalization, and the permitted exceptions. They include individual countries' commitments to lower customs tariffs and other trade barriers, and to open and keep open services markets. They set procedures for settling disputes.	Publications on trade and tariffs	https://www.wto.org/

0.C. Variables used for the current research

Topic	Variable	Description	Source
Key macro variables related to the containerized trade	Crude Oil in USD	West Texas Intermediate, also known as Texas light sweet, is a grade of crude oil used as a benchmark in oil pricing.	https://www.eia.gov/
	China Containerized Freight Composite Index (CCFI)	The index serves as a barometer of the liner shipping industry and it is computed based on data collected from 22 major international and domestic shipping companies for 11 major ports of departure in China.	Clarkson Research
	Clarksons Average Containership Earnings (\$/Day)	It is based on information provided by Clarksons brokers based on the number of the fully cellular containerships.	Clarkson Research
	Total Containership Fleet Development (Thousand TEUs)	The size of all containerships is estimated in Thousand TEUs.	Clarkson Research
	Index of Global Real Economic Activity	It is based on a global index of dry cargo single voyage freight rates of various bulk dry cargos such as grain, oilseeds, coal, iron ore, fertilizer, and scrap metal.	Kilian, 2009
Efficiency of Container Ports	Container Throughput (in TEUs)	Annual number of containers passing through a given port.	Websites of the Ports; Lloyd's List - Maritime Intelligence
	Information about the infrastructure of the ports	Surface of the container park in m ² , depth at berth in meters, number and type of gantry cranes, number of trucks, and number of forklifts and Reach stackers.	Ports' authorities websites and reports, scientific articles
Connectivity of container ports	Average size of ships (in TEUs)	Average size of containerships operating between each pair of ports	Lloyd's List - Maritime Intelligence
	Number of ships	Number of ships operating between each pair of ports	Lloyd's List - Maritime Intelligence
	Number of trips	Number of trips between each pair of ports	Lloyd's List - Maritime Intelligence
	Number of operators	Number of container carriers operating between each pair of ports	Lloyd's List - Maritime Intelligence
	Sea distance between two countries (in km)	Bilateral sea-distance between the main container ports in each country	Bertoli et al. (2016)
	Trade Direction	Direction of trade according to the national income of the country of departure and the country of arrival.	The World Bank
	Liner Shipping Bilateral Connectivity Index (LSBCI)	The LSBCI includes the following components for each pair of countries: the number of transshipments, the number of direct connections common, the geometric mean of the number of direct connections, the level of competition on services, and the size of the largest ships on the weakest route.	UNCTAD

Chapter 1. Factors behind the Freight Rates in the Liner Shipping Industry



Factors behind the Freight Rates in the Liner Shipping Industry

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Abstract

This paper analyses the relationship between the China Containerized Freight Index (CCFI), Containership Earnings, Fleet Development, bunker price and Global Economic Activity. The Markov-switching Vector Autoregressive model has been applied by assuming the existence of two regimes. The first one is characterized by low and volatile freight rates, while the second one is more stable with high earnings and high freight rates. Three major cycles in the liner shipping industry have been identified. Moreover, by applying the Impulse Responses Function, we have estimated the reaction of the freight rates following an increase of 1% of the other variables in the model.

Keywords: Freight rates, Container trade, Shipping, Vector Autoregressive Model

1.1. Introduction

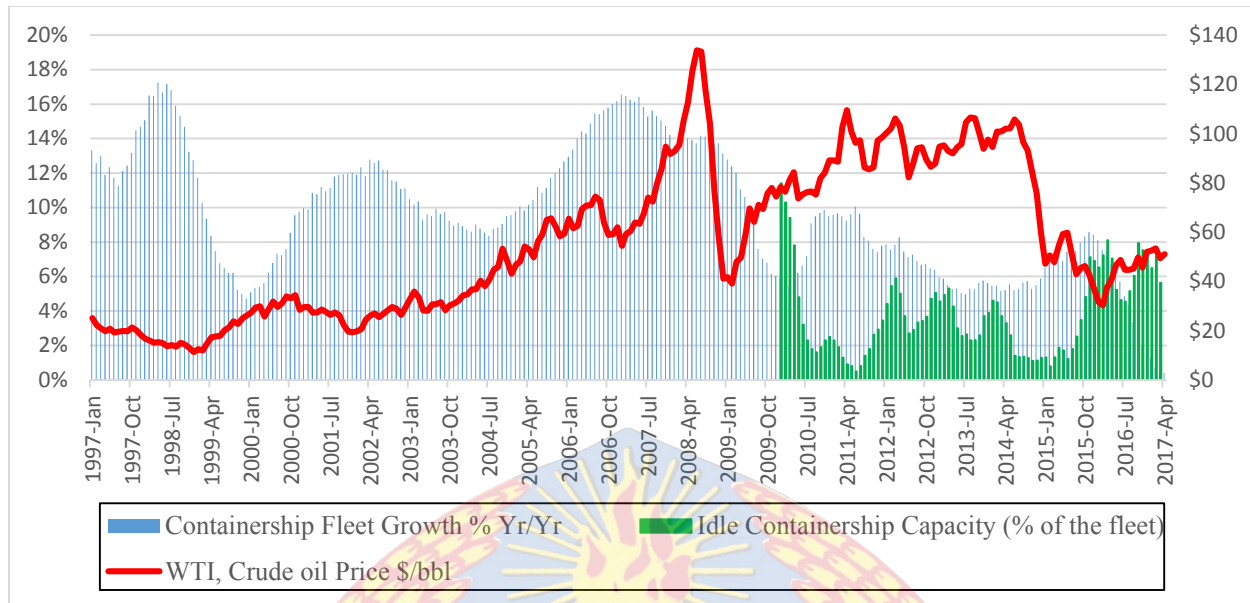
Maritime transport is of major importance for the world's economy as over 80% of the world's trade is carried by sea (UNCTAD, 2017). It is the cheapest and most efficient way to transport goods in large quantity. Since the 1960s, containerization has greatly reduced the expense of international trade and increased its speed, especially in consumer goods and commodities. It has also dramatically changed the ports' infrastructures and shipbuilding industry. Even though in 2016, containerized cargo accounted for only 16.7%⁵⁶ of the total volume of transported goods, its value is more than 60%⁵⁷. According to data of Clarkson Research, since 1990, the containerized trade has increased by more than 600%.

However, the industry can be characterized by a high level of vulnerability and cyclic pattern. Following the Subprime crisis, in 2009 container prices fell by 14% (UNCTAD, 2009) which was caused by the dramatic decrease of 10.8% of the cargo transported in containers. It was the first time since the invention of the containers that the World GDP grew faster than the World Seaborne Container Trade. Since then, the industry has been in an unstable state. In the last years, freight rates have been very low, ship values have plummeted and competition on the various trade routes has intensified (Rex et al., 2017). In February 2017, the 7th biggest shipping company Hanjin Shipping declared bankruptcy. It is a clear sign that even the big players in the industry are threatened by the current situation.

⁵⁶ Estimated by the authors based on the data collected from Clarkson Research Shipping Intelligence and UNCATD official websites.

⁵⁷ <http://www.worldshipping.org/about-the-industry/global-trade>

Figure 1.1: Containership Fleet growth, Crude oil price and Idle Capacity



Source: Clarkson Research

Prior to the subprime crisis, the price of oil was steadily increasing (Figure 1.1). On some major routes, shipping lines undertook different strategies with regard to the commercial speed of the fleet and the scale of the vessels (Notteboom and Vernimmen, 2009). Notteboom and Cariou (2009) estimated that by increasing the speed by two knots on average the fuel cost increases by around 40%. The high fuel prices gave incentives to shipping companies to invest in bigger ships and increase the time of travelling by reducing the speed and deploying more ships on some maritime routes. After the world crisis and the slowdown of the world economy, the excessive capacity seemed to have been a major concern for the industry. As shown in Figure 1.1, global idle container ship capacity represented 11.4% in January, 2010 and despite the decreasing trend of the fleet growth, it has remained relatively high (5.64% in March, 2017).

Freight Rates in the containerized industry have a direct impact on the shipping lines decisions and world trade. They can be defined as the price for transporting a standard 20-foot container from one port of origin to a destination port. However, analyzing on a macro level the factors behind the freight rates is not an easy task. The complexity arises from the fact that a large number of parties, each one with different objectives, is involved in container shipping (that is

consignor, a consignee, an ocean carrier, freight forwarders, inland carriers, banks, legal experts, insurance brokers, customs, port/terminal operators, and inland depot operators). Lee and Song (2017) classified them into service users and service providers. In addition, Container rates are quoted as the price per box, “Freight all Kinds”. This makes it even more complex to generalize how rates are structured spatially, because the tariffication is not related to the product being transported as in some other trades (Slack and Gouvelal, 2011).

Container freight rates can be broken down into three main components: Basic Ocean Freight (BAS), Mandatory surcharges and Value Added Services (VAS). BAS is mainly determined by the origin and destination of the cargo. Mandatory surcharges include a variety of charges that are added to BAS. For instance Bunker Adjustment Factor take into account the variation of the cost spent on fuel while Terminal Handling Charges are based on the cost of handling a container. Finally, VAS is related to the requirements of any particular client. Examples of such services are container cleaning and cold treatment. According to Maersk Line, BAS accounts for 50%, Mandatory surcharges for 25% and VAS for 25%⁵⁸. Slack and Gouvelal (2011) found out that surcharges account for more than 50% in the total freight charged to customers.

The objective of this paper is to analyze the relationship between key variables in the liner shipping industry by taking into account its cyclical and nonlinear patterns. Firstly, we depict some key findings and gaps in the literature regarding the ocean freight rates. Secondly, the methodology of Markov-Switching Vector Autoregressive (MS-VAR) models and the Impulse Response function are presented along with detailed description of each one of the selected variables. Thirdly, a detailed explanation of the different regimes as well as their switching probability are explained. This section of the paper also describes the six economic cycles that have been identified and the impulse responses of China Containerized Freight Index (CCFI) following a shock of another variable in the model. Finally, a summary of the main findings and possibility of future research are provided.

⁵⁸ Freight shipping rates and container costs, Official Website of Maersk Line
<https://www.maerskline.com/news/2017/08/03/rates-and-pricing>

1.2. Literature Review

Since the Subprime Crisis, freight rates in the liner shipping industry have been very volatile and many empirical studies have been conducted to understand its behavior. De Oliveira (2014) applied different methods of regressions, such as the random effects (RE) and fixed effects (FE), and the Hausman–Taylor (HT) estimator to analyze the freight rates. His study included 1,128 quotations for transporting a standard 20-foot container between six European countries and 47 partners. The independent variables in his model were the port-to-port distance, number of transshipments, economies of scale and Liner Shipping Connectivity Index. The results show that inward freight rates are on average, 23% higher than for outward ones, with the competition having a strong effect on the freight rates and surcharges appearing to be one of the main revenue-makers.

Slack and Gouvello (2011) analyzed the factors behind the freight rates in the case of 35 port destinations from Northern Europe. Their study shows that that distance is not a factor in explaining freight rates and the regional and temporal differences do not have any significant impact on the price of shipments. They also found that there is no correlation between the distance and BAF and no significant relationship between freight rates, imports and size of the large vessels.

..Behrens and Picard (2011) suggested that the impact of globalization as well as regional disparities on freight rates are overstated. The main reason for asymmetric freight rates is the presence of empty containers. Lun et al. (2013) used Path analysis in Structural Equation Modeling (SEM) to analyze the causality between the following variables: container trade, total fleet, freight rate, new building vessel price, second-hand vessel price, and demolition vessel price. The data is weekly for a period of twelve years, collected from Clarkson Research. Results suggest that there is significant relationship between total Fleet size and seaborne trade and no link between freight rate and seaborne trade. Tran and Haasis (2015) applied multiple regression to analyze the costs and revenues of the top 25 Container Operators. They found that market freight rate has an effect on revenue and the capacity has an impact on the total cost of the operators. Ordinary Least Square method was used by Duru and Yoshida (2011) to investigate the factors behind the Long term composite Freight Index (LFI), created by them and the seaborne trade. Their study shows that life expectancy is significant for both the models while the effect of fleet size is very weak.

Considering the nonlinear relations between the different factors influencing freight rates and their interdependence, some authors have applied different autoregressive models. Veenstra and Franses (1997) used the Multivariate Cointegration approach to analyze the relationship of six bulk freight rates related to different commodities and routes. A cointegration between five of the variables in the model was found and a VEC model was formulated. The stochastic trend of all variables show that an important part of the pattern of the freight rates cannot be predicted. Veenstra (1999) used the VAR model to examine the relation between spot and period freight rates for the ocean dry bulk shipping market. The research show the evidence of a term structure in the industry and all deviations from the present value relation are of a transitory nature. Chi (2016) applied the ARDL approach to build export and import models regarding the trade between China and US. Results reveal that gross domestic product is the key determinant of bilateral freight flows, while the real income is closely related to the bilateral freight flows. They also found that transport costs can be an important factor affecting the inflows of Chinese commodities to the US.

However the cyclic nature of the freight rates should also be considered. An appropriate approach is Markov Switching Vector Autoregressive model (MS-VAR) which allows us to analyze the relationship between the variables according to different states of the market. There are very few studies that have applied such a methodology in the context of ocean freight rates. Bildirici et al. (2015) analyzed the relation between GDP growth in US and the Baltic Dry Index (BDI) by assuming the existence of three regimes. The first one is associated with the crisis, the second one is the moderate growth regime and the third one is the high growth regime. They found that under the high growth regime, BDI improvement effects economic growth positively.

As seen from the literature review, most of the authors have focused on the ocean bulk freight rates. We have not found any study applying VAR methods to investigate the freight rates in the container trade. VAR modeling is widely applied in macroeconomics because it does not require as much knowledge about the forces influencing a variable as structural models with simultaneous equations. Its main advantage is that all variables are treated as endogenous and each one is explained by its lagged values, the lagged values of the other variables in the model and error terms. Thus, we can analyze the linear interdependence among multiple time series by avoiding the problem of endogeneity (an explanatory variable is correlated with the error term). A standard approach of VAR modelling is the estimation of the impulse responses function of each of the

variables to one unit increase in the current value of one of the VAR errors (Stock and Watson, 2001). Considering the current volatile freight rates and the oversupply in the industry, it is also important to investigate the potential structural changes in the containerized trade market.

Our paper aims to fill in this gap in the literature and to provide empirical application of MS-VAR and impulse responses function in the context of containerized trade market. The objective of the research is to identify the different business cycles that have occurred in the liner shipping industry in the last 13 years and to analyze their nature as well as to evaluate the effects on the container freight rates following a surprising increase in the oil price, earnings, Fleet Development or Global Economic Activity.

MS-VAR provides accurate estimates regarding the duration of each regime as well as the switching probabilities. Moreover, it allows one to distinguish different business cycles occurring during the observed period. For each regime we have computed the impulse responses of CCFI following a positive shock of another variable in the model.

1.3. Methodology

1.3.1. MS-VAR model

Following the pioneer work of Sims (1980), VAR modeling has become a useful tool in macroeconomics. Contrary to the structural models with simultaneous equations, VAR avoids the problems of over-identification (differentiating between correlation and causation by imposing restrictions). In VAR models, variables are endogenous. VAR provides a coherent and credible approach to data description, forecasting, structural inference, and policy analysis. In order to take into account the structural breaks in the time series and the different states that the containerized market operates, we combine the VAR approach with the Markov Chain process in the so-called Markov-switching Vector Autoregressive (MS-VAR) modelling.

Following (Hamilton, 1989), the general MS-VAR is depicted by equations (1) where it is assumed that a change in regime corresponds to an immediate one-time jump in the process mean. The description of MS-VAR in the current paper follows (Ehrmann et al., 2003). In our model, we consider that the mean would smoothly approach a new level after the transition from one regime to another. We do it in an extension of Hamilton's approach to a regime-switching VAR system (Krolzig, 2013).

$$Z_t = \begin{cases} v_1 + B_{11}Z_{t-1} + \dots + B_{p1}Z_{t-p} + A_1u_t & \text{if } s_t = 1 \\ \vdots \\ v_m + B_{1m}Z_{t-1} + \dots + B_{pm}Z_{t-p} + A_mu_t & \text{if } s_t = m \end{cases} \quad (1)$$

$$u \sim N(0; I_K)$$

where $Z_t = [Y_t F_t^1 F_t^2 F_t^3 F_t^4]^T$ refers to China Containerized Freight Composite Index (CCFI), West Texas Intermediate oil price, Clarksons Average Containership Earnings, Total Containership Fleet Development and Index of Global Economic Activity. These exogenous variables are explained by an intercept v_t , autoregressive terms of order p and a residual $A_t u_t$. The number of regimes in the model is two, $s_t = 2$, and all parameters are allowed to switch between the regimes. Therefore, each of the two regimes is defined by an intercept v_1 , autoregressive term $B_{1i}, \dots, B_{pi}$ and matrix A_t .

After the change in regime there is thus an immediate one-time jump in the variance of errors. This model is based on the assumption of varying processes according to the economic cycle in the liner shipping industry controlled by the unobserved variable s_t . Recall that in our model $s_t = \{1, 2\}$ is assumed to follow the discrete time and discrete state stochastic process of a hidden Markov chain and governed by transition probabilities $p_{ij} = \Pr(s_{t+1} = j | s_t = i)$, and $\sum_{j=1}^2 p_{ij} = 1 \forall i, j \in (1, 2)$. The conditional probabilities are collected into a transition matrix P as follows:

$$P = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix} \quad (2)$$

For a given parametric specification of the model, probabilities are assigned to the unobserved regimes conditional on the available information set which constitutes an optimal

inference on the latent state of the market (Girardin and Moussa, 2011). We thus obtain the probability of staying in a given regime when starting from that regime, as well as the probability of shifting to another regime. The classification of regimes and the dating algorithm used imply that every observation in the sample is assigned to one of the two regimes. We assign an observation to a specific regime when the smoothed probability of being in that regime is higher than 50%. The smoothed probability of being in a given regime is computed by using all the observations in the sample.

1.3.2. Impulse Response Function

In a MS-VAR model, with regime-dependence in the mean, variance and autoregressive parameters, a large number of parameters can switch between regimes. Ehrmann et al. (2003) suggest the use of regime-dependent impulse response functions which allow the investigation of how fundamental disturbances affect the variables in the model. For each regime, there is a set of impulse response functions. Each response function depends on the prevailing regime at the time of the shock. They facilitate the interpretation of switching parameters by providing a convenient way to summarize the information contained in the autoregressive parameters, variances and covariances of each regime (Girardin and Moussa, 2011). We follow the method of identification and estimation of impulse response proposed by Ehrmann et al. (2003).

..There are mK^2 regime-dependent impulse response functions which correspond to the reaction of K variable to K disturbances in regime m .

$$\frac{\partial E_t Z_{t+h}}{\partial u_{k,t}} \bigg|_{s_t=\dots=s_{t+h}=i} = \theta_{ki,h} \text{ for } h \geq 0 \quad (3)$$

Equation 3 shows the mathematical representation of the impulse response function for regime s . It reveals the expected changes in endogenous variables at time $t + h$ to one standard deviation shock to the k -th fundamental disturbance at time t in regime s . A series of K dimensional response vectors $\theta_{ki,1}, \dots, \theta_{ki,h}$ predict the response of the endogenous variables.

In order to make the precision of the impulse responses function more accurate, the bootstrapping technique was applied. This technique is used to create artificial observations for

the variables and use them for the same estimation procedures as the original dataset. The artificial histories are created by replacing the parameters in the model with their estimated variance-covariance matrix, and then calculating the endogenous variables (Ehrmann et al., 2003). However, in MS-VAR, applying the bootstrapping technique is complicated due to the existence of a hidden Markov-chain process which determines the regimes. Therefore, we first create a history for the regimes, and then we use it to continue for the endogenous variables. Ehrmann et al. (2003) proposed the following five steps to apply bootstrapping technique in the context of MS-VAR. Firstly, a history for the hidden regime s_t is created by replacing the exogenous transition matrix with its estimated value $\hat{P}$. At each time t , a random number is drawn from a uniform $[0,1]$ distribution and compared with the conditional transition probabilities to determine whether there is a switch of the regime. Secondly, a history for the endogenous variables is generated. All parameters in Equation 1 are replaced by their estimated values and new residuals are computed. Thirdly, we use the data of the artificial history to compute bootstrapped parameters $\{\tilde{v}; \tilde{B}_{1i}, \dots, \tilde{B}_{pi}; \tilde{\Sigma}_i\}$ for $i = 1, \dots, m$, the transition matrix $\tilde{P}$, and the smooth probabilities $\tilde{\xi} = \Pr(\tilde{s}_t = i)$ for $i = 1, \dots, m$ and $t = 1, \dots, T$. Fourthly, a set of restrictions are imposed which provide bootstrapped estimates of the matrices $\tilde{A}_1, \dots, \tilde{A}_m$. Finally, the bootstrapped estimates of the response vectors are computed.

1.3.3. Data

The following data have been selected: China Containerized Freight Composite Index (CCFI), Clarksons Average Containership Earnings (\$/Day), Total Containership Fleet Development (thousand TEUs), West Texas Intermediate oil price (\$/bbl) and the updated version of the index of global real economic activity. In total, there are 168 observations. The first three variables were collected from Clarksons Shipping Intelligence Network. Statistics regarding the price of crude oil were provided by the Energy and Information Administration of US (<https://www.eia.gov/>). The Global Real Economic Activity index was computed by (Kilian, 2009).

- China Containerized Freight Composite Index - CCFI (Index)

China (Export) Containerized Freight Index (CCFI) is sponsored by the Ministry of Communications of China and formulated by the Shanghai Shipping Exchange. The index serves as a barometer of the liner shipping industry and it is computed based on data collected from 22 major international and domestic shipping companies for 11 major ports of departure in China. The reliability of the data is ensured by a freight rate formulation committee composed by representatives of major domestic and foreign shipping companies. This is the key variable in the research and it is denoted as CCFI in our analyses.

- Clarksons Average Containership Earnings (\$/Day)

Clarksons Average Containership Earnings is based on information provided by Clarksons brokers on a daily and weekly basis. This information is used to calculate the earnings in the liner shipping industry by taking into account the number of the fully cellular containerships. Clarkson Research compute earnings based on a single freight rate. This indicator is a proxy for the profitability in the container shipping industry. In our research, this variable is denoted as “Earnings”. In broad terms, earnings for each route are calculated by taking the total revenue, deducting current bunker costs based on prices at representative regional bunker ports, estimated port costs (after currency adjustments) and total commission and then dividing the result by the number of voyage days (Clarkson Research, 2015).

- Total Containership Fleet Development (Thousand TEUs)

The size of all containerships is estimated in TEUs. This variable refers to the supply of the Liner Shipping. In the current paper we refer to this variable as “Fleet”.

- West Texas Intermediate oil price (\$/bbl)

West Texas Intermediate, also known as Texas light sweet, is a grade of crude oil used as a benchmark in oil pricing. The bunker cost accounts for 70% of the operational cost of carriers and thus WTI could be used as a proxy for the operational costs of the carriers.

- Global Real Economic Activity (index)

The index of global real economic activity is computed from data collected from the monthly report on "Ship and Economics" published by Drewry Shipping Consultants Ltd. It is based on a global index of dry cargo single voyage freight rates of various bulk dry cargos such as grain,

oilseeds, coal, iron ore, fertilizer, and scrap metal. The index can be traced back to 1968 and it is a direct measure of global economic activity which does not require exchange-rate weighting. It automatically aggregates real economic activity in all countries and incorporates shifting country weights, changes in the composition of real output, and changes in the propensity to import industrial commodities for a given unit of real output (Kilian, 2009).

1.4. Empirical Results

1.4.1. Descriptive statistics and specifications of MS-VAR

We use monthly time series from March 2003 to February 2017. Table 1.1 provides a summary of the descriptive statistics for all variables. The average values of all indicators are positive. Standard Deviation is very high for the Crude oil, Earnings, and Global activity. According to the results of Skewness and Kurtosis, most of the variables are symmetrically distributed except CCFI and Global Activity. In addition, the Jarque–Bera test confirms these results and accepts the normality hypothesis. In order to check whether each variable follows a unit-root process, we applied the Dickey–Fuller test. The unit root test of Augmented Dickey Fuller test clearly rejects the null hypothesis of the stationarity of all variables except Global Activity. It means that all variables except Global Activity have a unit root and are generated by a stochastic process.

Table 1.1: Descriptive statistics

	Min	Max	Mean	S. dev.	Med.	Kurtosis	Skewness	JB test *	ADF test**
CCFI	641.5040	1315.8740	1.0309e+03	140.7295	1060.5850	3.3858	-0.9034	23.8936 (1.7019e-03)	0.0000 (4.7803e-01)
EARNINGS	4395.7770	28650.8608	1.2237e+04	6866.1563	10142.5182	2.2824	0.6766	16.4238 (4.6844e-03)	0.0000 (3.6586e-01)
FLEET	6163.6750	20043.4390	1.3140e+04	4410.1717	13097.9290	1.7259	-0.0394	11.4069 (1.1359e-02)	0.0000 (9.9900e-01)
CRUDE OIL	28.1100	133.8800	7.0221e+01	25.0233	69.5400	2.0869	0.1636	6.5850 (3.6691e-02)	0.0000 (5.1096e-01)
Global Activity	-133.1265	66.7783	1.0220e+01	35.9535	18.1813	3.7078	-0.7674	19.9951 (2.7876e-03)	1.0000 (3.8479e-02)

* In brackets, critical values for the tests. ** Augmented Dickey-Fuller test.

Source: Authors' calculations

Correlation coefficients for the whole sample are presented in Table 1.2. It shows that all variables in the model have a positive correlation with CCFI except the Fleet. However the correlation coefficients are less than 50%. The strong and negative correlation between Earning and Fleet (-0.80) suggests a possible negative effect of the growing capacity in the shipping industry on the Earnings. There is also a negative correlation of 75% between Fleet and Global Activity.

Table 1.2 Correlation Matrix

	CCFI	Earnings	Fleet	Crude Oil	Global Activity
CCFI	1				
Earnings	0.4369	1			
Fleet	-0.4613	-0.7975	1		
Crude Oil	0.3906	-0.2051	0.2811	1	
Global Activity	0.4553	0.6475	-0.7538	0.0962	1

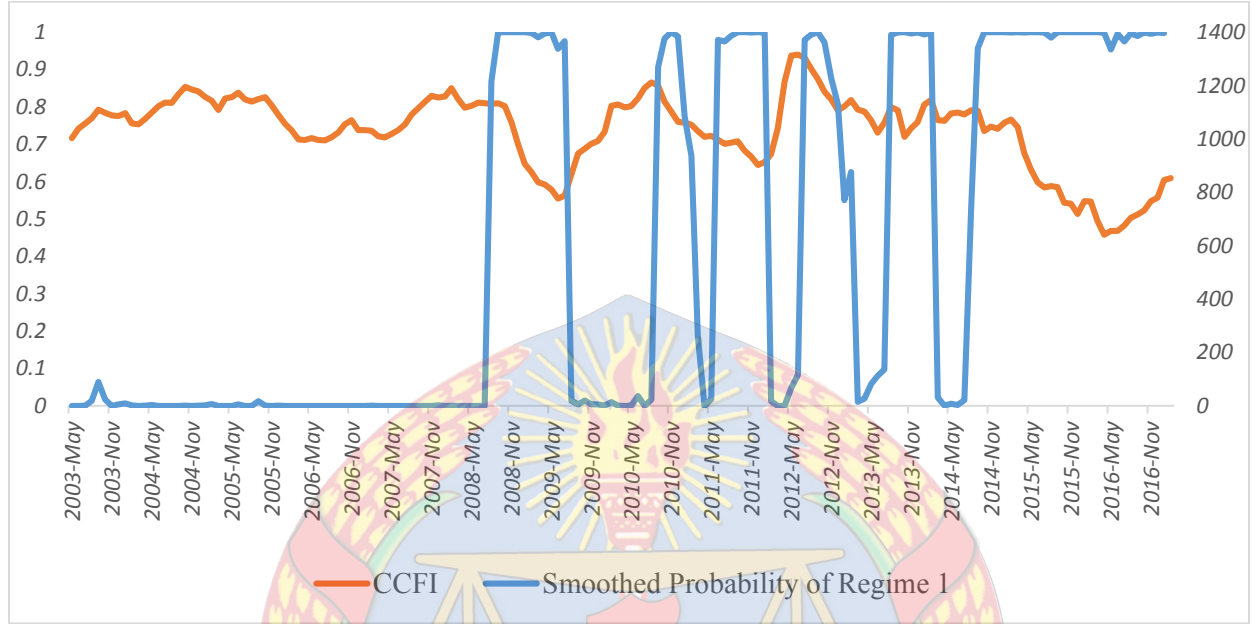
Source: Authors' calculations

In the MS-VAR model and impulse response functions, all variables were transformed into log and we use their growth rates for our analysis. Following the results of the Augmented Dickey–Fuller test, we also transform all variables into first difference, except Global Activity. In the current paper we estimate an unrestricted MS-VAR model with intercept and without trend. We choose 2 lags based on the AIC, HQ and SC criteria. We also assume the existence of two regimes.

1.4.2. Business Cycles in the Liner shipping industry

As we have already emphasized, the MS-VAR model allows us to identify the different business cycles that have occurred from May 2003 to February 2017 (we have included two lags in the model). Figure 1.2 shows the transitional switching probabilities of regime 1 (the blue line) as well as the value of the CCFI (the red line).

Figure 1.2: Smoothed probability of Regime 1 (volatile and decreasing freight Rates) and CCFI index. Source: Author's drawing



In the MS-VAR model, all variables were transformed into log and we use their monthly growth rates. The blue line shows the switching probability of the more volatile Regime 1. The red line depicts CCFI.

Both regimes are very persistent as shown in the matrix below. The regime switching probabilities for Regime 1 and Regime 2 are 18% and 17%, respectively. A major event that marks the switch of the regime 2 to regime 1 is the Subprime Crisis. The switch occurs in September 2008 and has a major impact on the variables in the model.

$$P = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix} \text{ with } P = \begin{pmatrix} 0.8151 & 0.1849 \\ 0.1697 & 0.8307 \end{pmatrix}$$

Throughout the observed period, Regime 1 and Regime 2 last 71 and 95 months, respectively. Figure 1.2 and Table 1.4 show the descriptive statistics of the variables under each of the identified regimes. Regime 1 is characterized by lower average container freight rates and considerably higher volatility (Standard Deviation). Moreover, under the second regime the average Global Activity is negative (-15.2), while in regime one, its mean value is 29.32. Earnings are also considerably higher under the second regime (15,908). On the other hand, the mean and

the standard deviation of the Fleet are higher in the first regime. It suggests, that Regime 1 is characterized by a low level of economic activity, a high level of volatility of freight rates, a low level of earnings and a high growth rate of the containership capacity. The second regime is slightly more persistent than the first one and can be defined as a regime of a high level of economic activity, high and stable container freight rates, a high level of earnings and a low level of fleet capacity.

Table 1.3: Descriptive Statistics of Regime 1

	CCFI	Earnings	Fleet	Crude Oil	Global Activity
Min	641.50	4,619.34	11,926.45	30.32	-133.13
Max	1,263.72	1,5740.16	20,043.44	106.29	44.45
Average	943.04	7,310.74	16,677.73	69.88	-15.42
Std. Dev.	161.10	2,344.44	2,679.00	23.65	32.54
Med	956.77	6,461.60	17,084.64	69.64	-15.28
Kurtosis	-1.12	1.85	-1.18	-1.62	1.66
Skewness	0.15	-1.47	0.32	-0.01	0.84

Source: Authors' calculations

Table 1.4: Descriptive Statistics of Regime 2

	CCFI	Earnings	Fleet	Crude Oil	Global Activity
Min	946.37	4,395.78	6,257.82	28.11	-29.43
Max	1,315.87	28,650.86	17,872.49	133.88	66.78
Average	1,097.40	15,908.95	10,642.82	71.30	29.32
Std. Dev.	74.32	6,906.49	3,524.77	25.72	25.35
Med	1,097.94	16,205.72	6,501.78	30.34	42.01
Kurtosis	0.50	-0.86	-0.92	-0.55	-0.22
Skewness	0.48	-0.16	0.57	0.24	-0.80

Source: Authors' calculations

By looking at Figure 1.2 we can distinguish three economic cycles. The first one is from May 2003 to August 2008 which falls under Regime 2. This period can be characterized by steady growth, very low volatility of CCFI, a high level of earnings, a low price of crude oil and a very high level of Global Activity (Table 1.5). This is the longest period which falls uniquely under the second regime (64 months).

Table 1.5: Business Cycle 1: Steady Growth

	CCFI	Earnings	Fleet	Crude Oil	Global Activity
Min	995.21	14,315.05	6,257.82	28.11	17.80
Max	1,194.93	28,650.86	11,824.90	133.88	66.78
Average	1,094.43	20,011.35	8,506.10	62.41	41.45
Std Dev.	59.38	3,879.29	1,682.30	25.75	14.42
Median	1,098.37	18,893.90	8,169.19	59.35	42.99

Source: Authors' calculations. Descriptive statistics (May 2003 - August 2008)

The effect of the Subprime Crisis on Containerized trade started in September 2008, when we have a switch from Regime 2 to Regime 1. This marks the beginning of the second business cycle, which is characterized by a high level of uncertainty. This cycle continues until August 2014 (72 months in total). Throughout this period we have frequent switches between the two regimes. Even though the average CCFI has decreased by only 3% compared to the previous cycle, its volatility has increased by 102%. Earnings and Global Activity also had a dramatic decrease of 62% and 95%, respectively (Table 1.6). This period could be characterized as a post-crisis period where government took considerable measures to support the industry and to maintain economic growth. This business cycle lasts 72 months.

Table 1.6: Business Cycle 2 - Uncertainty

	CCFI	Earnings	Fleet	Crude Oil	Global Activity
Min	777.04	4,395.78	11,926.45	39.09	-41.27
Max	1,315.87	15,740.16	17,872.49	109.53	44.45
Average	1,057.41	7,504.49	14,884.93	86.40	2.19
Std. Dev.	119.77	2,725.36	1,776.50	16.82	24.20
Median	1,066.60	6,537.33	15,066.53	89.33	2.69

Source: Authors' calculations. Descriptive statistics (September 2008 - August 2014)

From September 2014 to February 2017, we observe a business cycle which falls entirely under Regime 1 and we have named it “The New Normal” which lasts 30 months. During this period, the average Global Activity decreased by 39.52 points (Table 1.7). The average CCFI is 21% lower than the second business cycle and its volatility is 20% higher. Earnings became less volatile and decreased by 7% compare to the previous cycle. The Fleet has increased by 30% and its volatility is 58% lower. In April 2016, CCFI registered its lowest monthly value ever recorded, 641.50 points, and in August 2016 the Hanjin Shipping, the seventh biggest shipping company, declared bankruptcy.

Table 1.7: Business Cycle 3: The new Normal,

	CCFI	Earnings	Fleet	Crude Oil	Global Activity
Min	641.50	5,357.11	17,926.47	30.32	-133.13
Max	1,107.11	10,935.99	20,043.44	93.21	2.18
Average	834.42	6,978.76	19,302.69	50.69	-37.33
Std Dev.	143.40	1,729.89	743.40	13.65	30.08
Median	799.92	6,156.18	19,657.97	47.52	-33.49

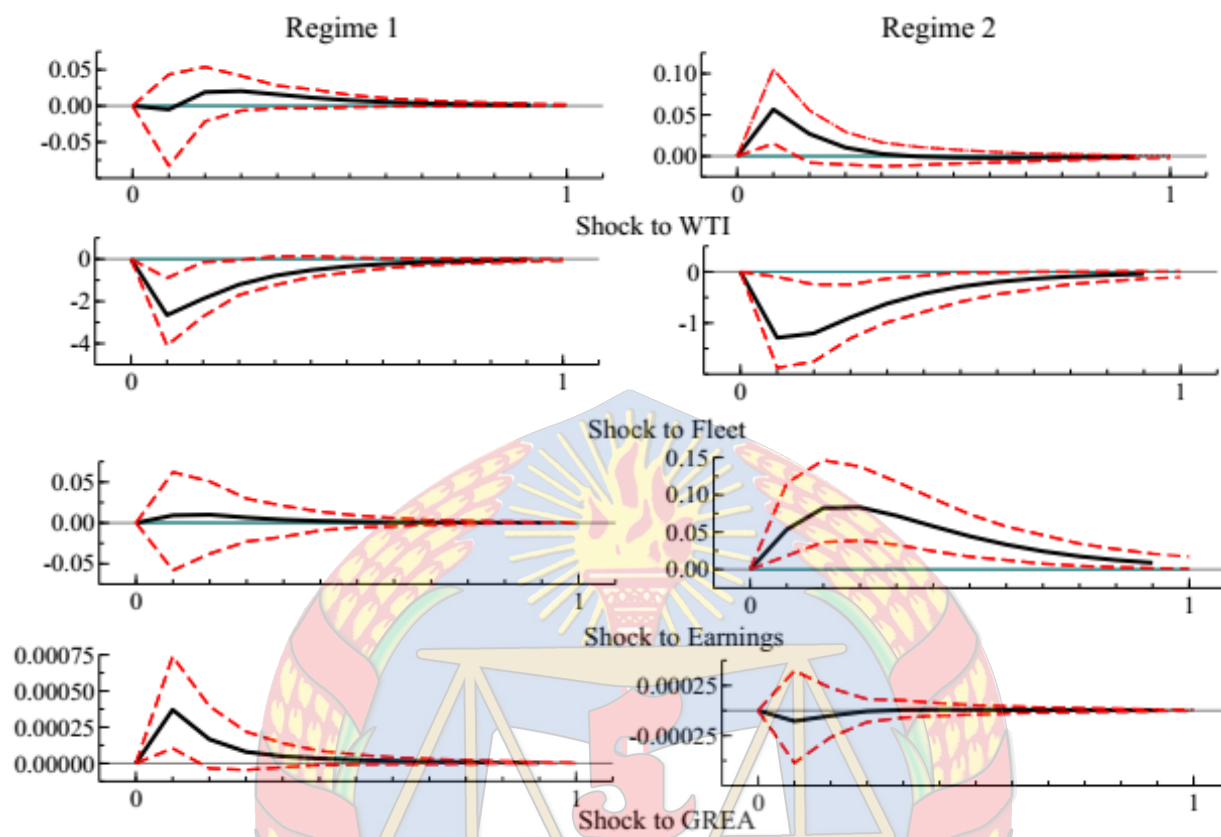
Source: Authors' calculations. Descriptive statistics (September 2008 - August 2014)

The proposed MS-VAR model tracks well different cycles that have occurred in the liner shipping industry. Both regimes are very persistent, which allows us to assume that the last business cycle, “The New Normal” might continue for at least a few more years. The growing number of conferences between carriers is a clear sign that shipping companies are trying to minimize their costs in order to deal with the low world demand and high level of containership capacity. We also observe a monopolization of the shipping market. According to Alphaliner, in 2008 Maersk had a share of around 6% of the world fleet, while in April 2017, it was more than 16%.

1.4.3. Impulse Responses Functions

We use impulse response functions to show how the endogenous variables react to shocks of one standard deviation of the residuals of each equation (Crude Oil, Earnings, Fleet or Global Activity). The Impulse response functions are conditional on a given regime prevailing at the time of the disturbance and throughout the duration of the response (Ehrmann et al., 2003). In order to increase the precision of our estimation, we have applied the standard bootstrapping techniques. This method consists of increasing the number of observations by creating artificial histories for the variables. We have made 1000 bootstrap replications. Similarly to Uhlig (2005) and considering the findings of Inoue and Kilian (2016), we use a confidence interval of 68%. In the appendices 1.A, 1.B, 1.C and 1.D are shown the results with of Impulse Responses Functions for the other variables.

Figure 1.3: Response of CCFI reacting to shock to the other variables in the MS-VAR model according to the two regimes.



Source: Authors' calculations

Note: The variables were transformed in log and we use their growth rate for the analysis. Impulse response functions of CCFI are conditioned to the prevailing regime. The figure depicts responses of CCFI to a positive shock of 1% to the other variables in the model. The impulse reaction period is chosen to be 12 months. Solid black lines depict impulse responses of CCFI, while dashed lines depict 68% confidence intervals. The upper dashed and lower dashed lines represent 84% quantile and the 16% quantile of the posterior distribution, respectively. Impulse responses are computed on the basis of 1000 bootstrap replications. GREa refers to Global Real Economic Activity Index while WTI refers to the price of Crude Oil.

The response of CCFI to a one standard deviation shock to the other variables in the model are shown in Figure 1.3. Responses are regime dependent: the left-hand diagrams correspond to Regime 1 (high volatility and decreasing freight rates) whereas the right-hand figures refer to Regime 2 (low volatility and high container freight rates).

A positive shock of 1% of the crude oil has a significant effect on CCFI only in the second regime. This could be explained by the fact that most of the observations which fall under the

second regime (stable growth) are before September 2008. During that time, the oil price had an increasing trend (see Figure 1.1) and thus the freight rates were strongly associated with the bunker price. On the other hand, throughout Regime 1 which is post crisis regime, the price of crude oil is quite low and has a decreasing trend.

The size of the world Fleet has substantial impact in both regimes. It is more pronounced in Regime 1, where a 1% increase of the size of the fleet leads to an immediate 3% decrease of the container freight rates. Then it takes around 7 months for CCFI to go to its equilibrium level. In the second regime, the shock of the Fleet is also significant and CCFI decreases by approximately 1.4%. These results suggest that the supply in the shipping industry plays a major role in the container freight rate price formation. During a period of growth and low volatility, companies are able to better plan their strategies in terms of fleet development, while during a period of crisis, we have a substantial decrease in the demand for container transport which drives the freight rates down. Shipping companies are trying to optimize their fleet by renewing their fleets. According to the data of Clarkson research, between March 2003 and August 2008, the monthly average of scrapped vessels were 3,257 TEUs, while from September 2009 to March 2017, the monthly average was 16,138 TEUs, which is the equivalent of one Triple E containership. In January 2014, the equivalent of demolished ships was 84,740 TEUs, the highest level ever recorded. We should emphasize that many environmental and safety regulations also play a role in the increase of scrapping activities.

1.5. Conclusion

This paper contributes to the existing literature by exploring the relationship between the China Containerized Freight Index (CCFI), Clarksons Average Containership Earnings, Fleet Development, the price of Crude Oil and Global Real Economic Activity by applying MS-VAR and Impulse response function approaches. We have applied the MS-VAR model without trend and intercept by assuming the existence of two regimes. The first one can be characterized as a regime of crisis, low freight rates and high volatility occurring after the Subprime crisis, while the second one is a state of steady growth and low volatility in the shipping industry. The identified

regimes are very persistent and track well the trends and business cycles in the shipping industry between May 2003 and February 2017. We have identified 3 major business cycles. The first one is characterized by a period of long and steady growth which lasts until August 2008. The following cycle is a transitional one which lasts 6 years. The third cycle is characterized by very low freight rates, low earnings and substantial size of the world fleet.

The impulse responses methodology allows us to pin down the consistent and efficient estimates of the reaction of CCFI to different factors according to the two states of the industry (Regime 1 and Regime 2). The variable which has a profound negative impact on the container freight rates is the growth of the world fleet. Its effect is more pronounced under the regime of crisis. Earnings in the shipping market and the crude oil price are only significant in the second regime and both have a positive impact on CCFI. The Global Economic activity has a minor effect on CCFI in the regime of crisis.

Potential future research could include the use of another indicator as a proxy for freight rates instead of CCFI. In this way we could double check our findings. Moreover, a variable which depicts the market concentration in the liner shipping industry (for example, the share of the top 10 companies in terms of transported TEUs) could also be included in the model. Other variables which reflect the Economic activity worldwide such as the industrial production of OECD member states could be also be considered.

The last identified economic cycle (“The New Normal”) is characterized by low container freight rates, low earnings, high fleet capacity and relatively low crude oil prices. Shipping companies are dealing with this unstable prospect of the market by limiting their operational costs (that is slow steaming strategies and economies of scale) and sharing capacity (creation of alliances). As UNCTAD pointed out, the market has become more monopolized and small players are vulnerable. In addition, even the big companies, such as Hanjin Shipping, could face bankruptcy. When we take into account the regionalization of the trade (for example, ASEAN Economic Community, Trade agreement between the EU and Canada, etc.) and the slowdown of the Chinese economy, it is obvious that the current unstable situation of “New Normal” might last a few more years.

1.6. References

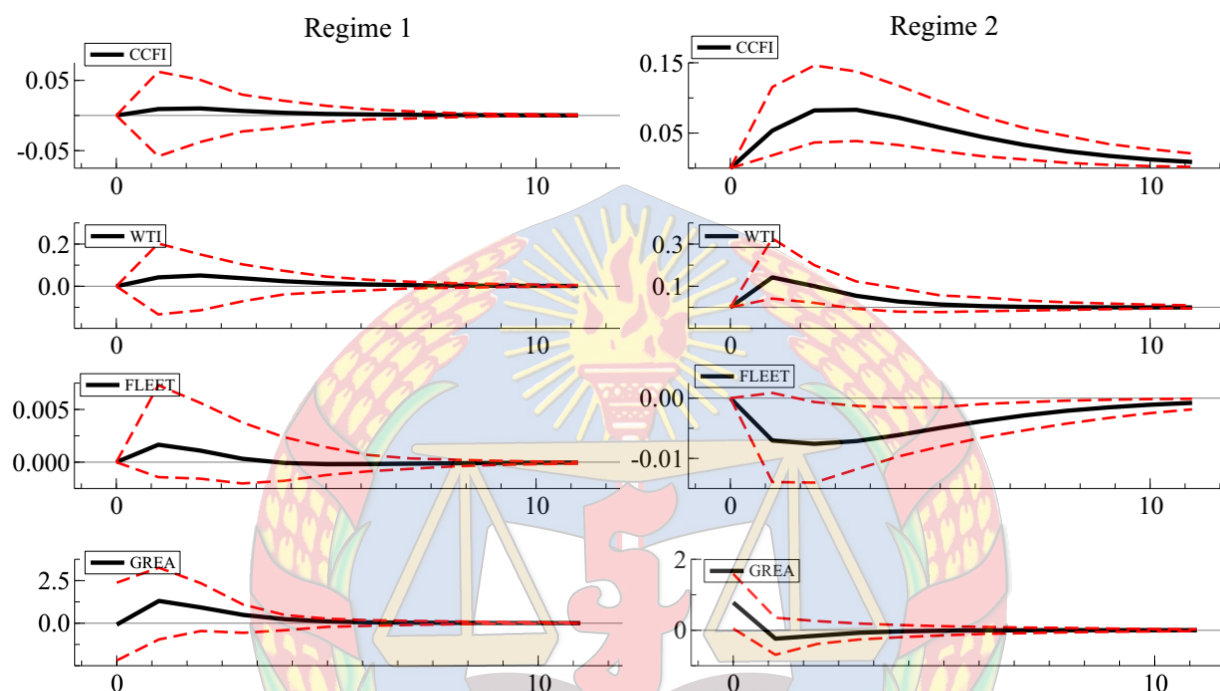
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1.7. Appendices

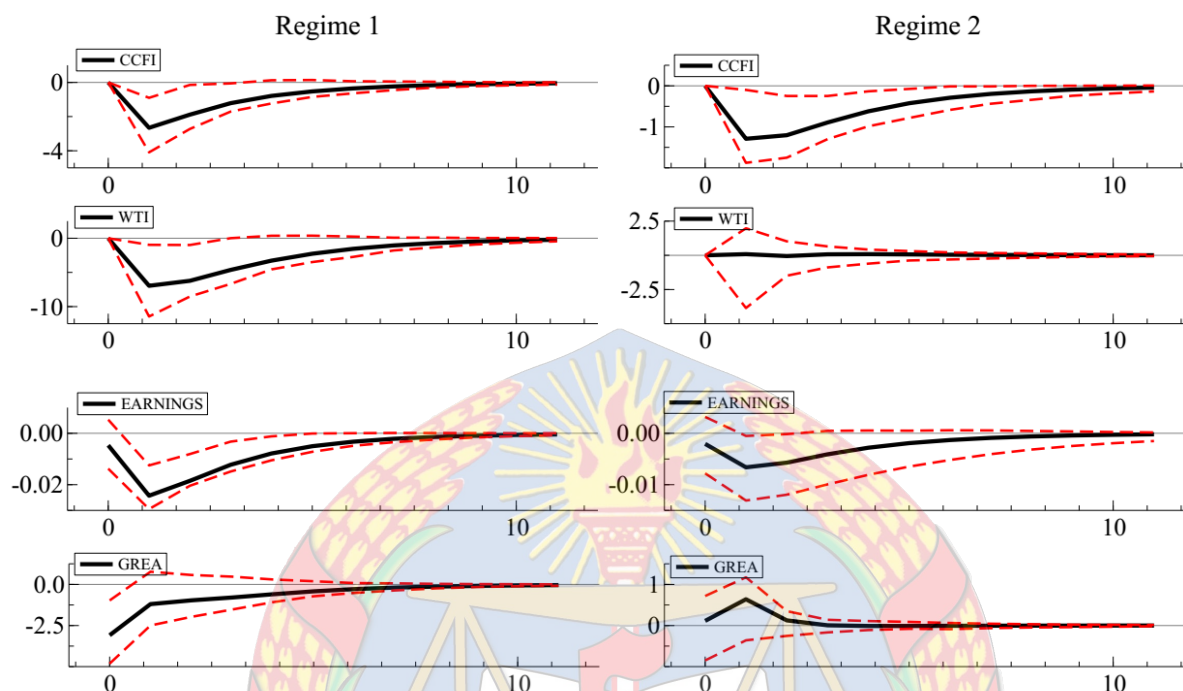
1.A. Response of Earnings reacting to shock to the other variables in the MS-VAR model according to the two regimes



Source: Authors' calculations

Note: The variables were transformed in log and we use their growth rate for the analysis. Impulse response functions of Earnings are conditioned to the prevailing regime. The figure depicts responses of the Earnings to a positive shock of 1% to the other variables in the model. The impulse reaction period is chosen to be 12 months. Solid black lines depict impulse responses of Earnings, while dashed lines depict 68% confidence intervals. The upper dashed and lower dashed lines represent 84% quantile and the 16% quantile of the posterior distribution, respectively. Impulse responses are computed on the basis of 1000 bootstrap replications. GREA refers to Global Real Economic Activity Index while WTI refers to the price of Crude Oil.

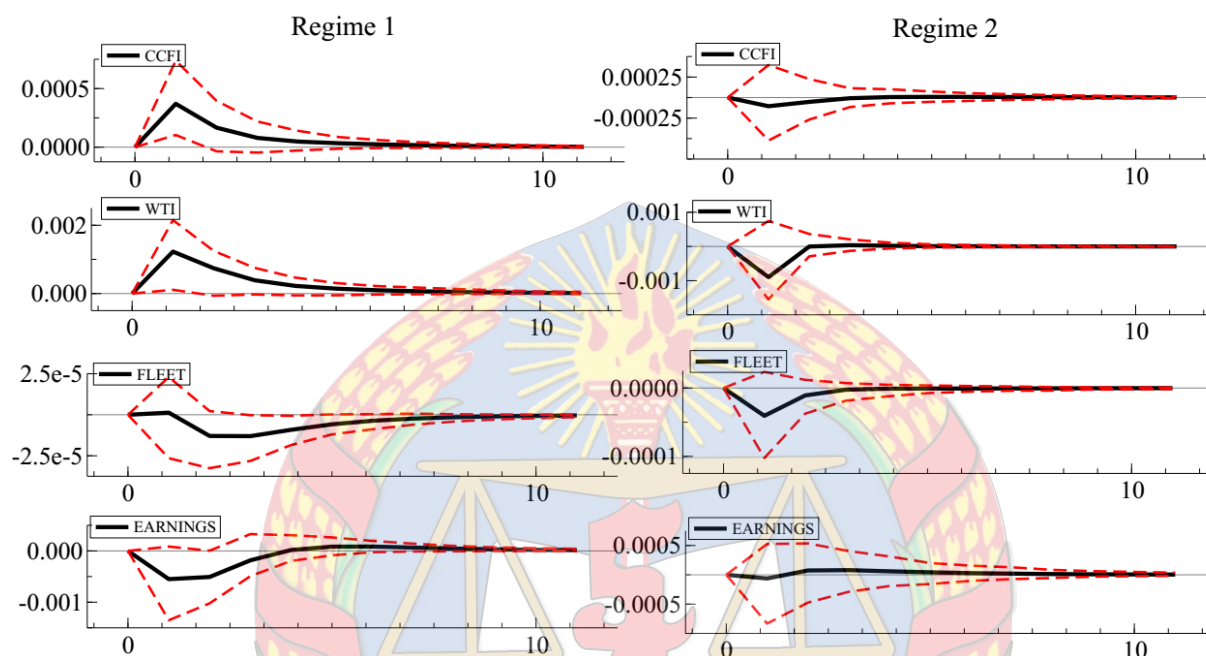
1.B. Response of Fleet reacting to shock to the other variables in the MS-VAR model according to the two regimes



Source: Authors' calculations

Note: The variables were transformed in log and we use their growth rate for the analysis. Impulse response functions of Fleet are conditioned to the prevailing regime. The figure depicts responses of the Fleet to a positive shock of 1% to the other variables in the model. The impulse reaction period is chosen to be 12 months. Solid black lines depict impulse responses of Fleet, while dashed lines depict 68% confidence intervals. The upper dashed and lower dashed lines represent 84% quantile and the 16% quantile of the posterior distribution, respectively. Impulse responses are computed on the basis of 1000 bootstrap replications. GRE refers to Global Real Economic Activity Index while WTI refers to the price of Crude Oil.

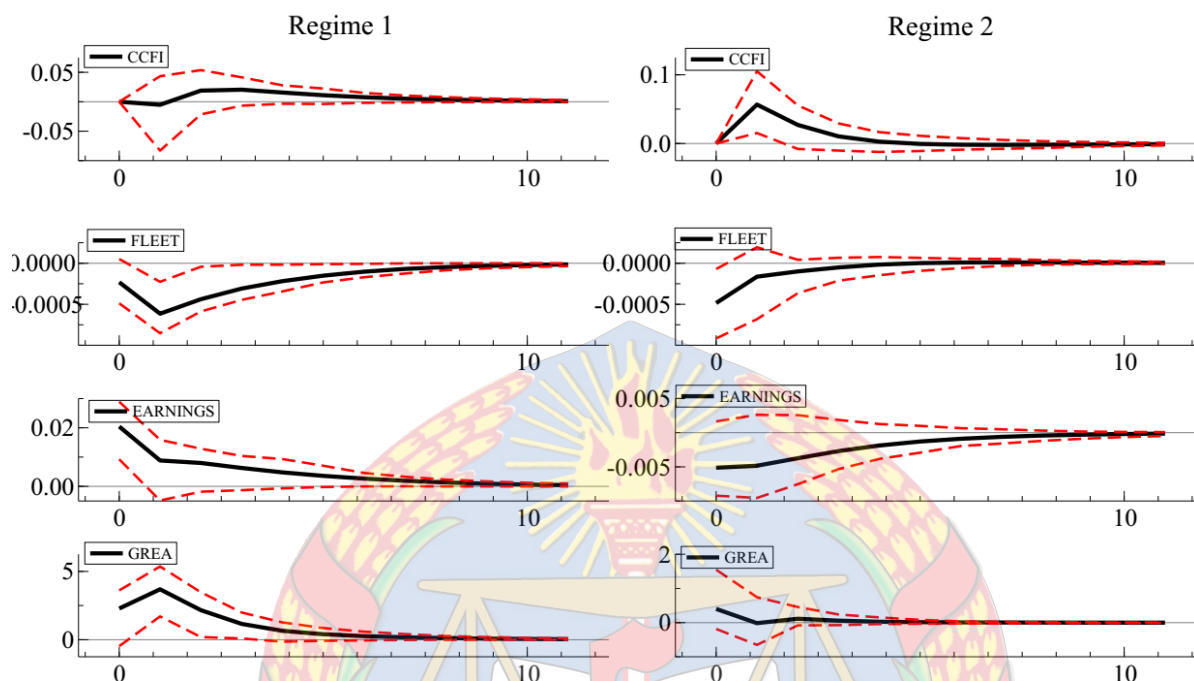
1.C. Response of Global Real Economic Activity (GREA) reacting to shock to the other variables in the MS-VAR model according to the two regimes



Source: Authors' calculations

Note: The variables were transformed in log and we use their growth rate for the analysis. Impulse response functions of Fleet are conditioned to the prevailing regime. The figure depicts responses of GREA to a positive shock of 1% to the other variables in the model. The impulse reaction period is chosen to be 12 months. Solid black lines depict impulse responses of GREA, while dashed lines depict 68% confidence intervals. The upper dashed and lower dashed lines represent 84% quantile and the 16% quantile of the posterior distribution, respectively. Impulse responses are computed on the basis of 1000 bootstrap replications. GREA refers to Global Real Economic Activity Index while WTI refers to the price of Crude Oil.

1.D. Response of the price of Crude oil (WTI) reacting to shock to the other variables in the MS-VAR model according to the two regimes



Source: Authors' calculations

Note: The variables were transformed in log and we use their growth rate for the analysis. Impulse response functions of WTI are conditioned to the prevailing regime. The figure depicts responses of WTI to a positive shock of 1% to the other variables in the model. The impulse reaction period is chosen to be 12 months. Solid black lines depict impulse responses of WTI, while dashed lines depict 68% confidence intervals. The upper dashed and lower dashed lines represent 84% quantile and the 16% quantile of the posterior distribution, respectively. Impulse responses are computed on the basis of 1000 bootstrap replications. GREY refers to Global Real Economic Activity Index while WTI refers to the price of Crude Oil.

Chapter 2. Container Port Hierarchy and Connectivity Based On Network Analysis



Container Port Hierarchy and Connectivity based on Network Analysis

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Abstract

This study aims to analyze port hierarchy between 153 container ports. For this purpose, a network analysis was conducted. Particular attention was paid to 68 ports from the ASEAN+3⁵⁹ community. We have created five director weighted networks at both port and country levels. Results reveal that the prevailing structure of the global maritime network is hub and spoke, and that the port rankings change according to different centrality measures. Regarding the intra-ASEAN+3 connectivity, ASEAN member states form a cluster of interconnected ports. A comparative analysis shows that both the Export and Maritime connectivity networks have similar patterns, which indicates that the containerized trade within ASEAN+3 has the same features as the intra-regional exports.

Keywords: Network Analysis, ASEAN, Trade, Shipping, Connectivity, Centrality

⁵⁹ Member States of the Association of Southeast Asian Nations (ASEAN), the People's Republic of China, Japan, and the Republic of Korea.

2.1. Introduction

Maritime transport is the cheapest and most efficient way to transport goods in large quantities. According to data from Clarkson Research, containerized trade has increased by more than 600% since 1990. This has dramatically changed the character of ports' infrastructure. Due to the expansion of ports' hinterlands, shipping lines have been able to streamline their itineraries by reducing the number of ports of call, creating load-centre ports (hub ports). It also induced a further increase in vessel size, along with a growth in terminal area (Midoro et al., 2005). Indeed, Notteboom (2010) stated that 'the success of the port is strongly affected by the ability of the port community to fully exploit synergies with other transport nodes.

Furthermore, the maritime network is a complex subject due to the fact that its prevailing structure is 'hub and spoke'. Asgari et al. (2013) define a hub port as a port that connects regional ports (feeder lines) to other hub ports (global network). Such hub ports might exhibit different purposes or importance within a network. Some ports such as Singapore and Hong Kong have a strategic geographical position and play an important intermediate role in connecting other regional ports to major sea trade routes, while others like Shenzhen are a gateway to large manufacturing centres situated in the hinterland (Wang and Cullinane, 2016). Therefore, analysing the position and the purpose of a port within a network is essential to understanding the nature of the liner shipping network.

According to the International Maritime Organization, over 90% of the world's trade is carried out via sea. Hence, it is interesting to analyze whether a network based on the maritime connectivity has similar features to the network related to the value of countries' total exports. An interesting case study is the ASEAN+3⁶⁰ community which aims to promote regional economic integration in Eastern and South-Eastern Asia. According to Tongzon and Lee (2015) this integration may result in lower shipping costs and improved quality of shipping throughout the

⁶⁰ ASEAN+3 community includes all member states of the Association of Southeast Asian Nations (ASEAN), the People's Republic of China, Japan, and the Republic of Korea.

region, and thus contribute to an improvement in the ASEAN members' trade performance and international competitiveness.

This research aims to determine the characteristics of the maritime and trade networks at port and country levels by using the graph theory and centrality measures. For this purpose, a dataset of 153 ports from 50 countries, including statistics for 6,410 maritime routes in the year 2014, was used. Particular attention was paid to a subset of 68 ASEAN+3 ports, including 38 designated ports of the ASEAN Single Shipping Market (ASSM). This paper attempts to answer the following research questions: What are the characteristics of the global maritime shipping network? What are the key ports in the network and what is their main purpose (transshipment port, gateway port, regional port, etc.)? What is the position of the ASEAN community in the global shipping network? How are the regional maritime connectivity networks at port and country levels organized within the ASEAN+3 community? Are there any fundamental differences between maritime connectivity and countries' exports of all goods?

The remainder of this paper is as follows: Section 2 discusses the literature related to ports' connectivity and maritime trade. Section 3 explains the methodology related to the Network Analysis and the dataset used in the study. All results are depicted in Section 4. Lastly, a discussion on the outcomes of the study is provided in the final section.

2.2. Review of the literature

2.2.1. Network Analysis in the context of maritime transport

While the main ports and shipping routes have been described in a number of studies, the structure and evolution of the global maritime network, as well as some crucial issues such as unequal traffic distribution and port hierarchies, has not been fully documented (Ducruet and Notteboom, 2012, Ducruet, 2013). It is important to analyze the ports' connectivity because even a small change in the network can cause shipping carriers to modify their shipping routes in order to meet the demands of the shipping markets (Peng et al., 2016). A suitable method to measure the connectivity of container ports is Network Analysis. It allows for the identification of port clusters,

which may result in agglomeration economies and a strengthened bond between individual and organizational linkage networks (Yang et al., 2016). Such an analysis is a good complement to traditional measures of individual throughput (Ducruet et al., 2010).

The cost effectiveness and production efficiency of ports are closely linked to the optimization of their networks. John et al. (2016) applied Bayesian belief networks to identify various influencing variables related to different risk factors in a seaport system. Peng et al. (2016) used a mixed-integer nonlinear stochastic programming model and showed that the deployment of the containers handled at each seaport was not directly related to its throughput capacity. In a study conducted by Wang and Cullinane (2016), Freeman's centrality measures were estimated in order to determine the importance of a given port at both regional and global levels. The degree centrality measures revealed that the key port in the network was Shenzhen. In terms of closeness centrality, which is related to the number of connections with diverse ports, Shanghai, Hong Kong and Singapore had the highest scores. In addition, the betweenness centrality measures pointed out that Hong Kong and Singapore are also hubs connecting different clusters of tightly connected ports.

Notteboom (2010) conducted a detailed container traffic analysis for the period 1985–2008 for 78 ports. His study showed that the performance of European ports was related to their position within supply chains and networks. There is also a gradual deconcentration process in the container handling market, though it remains more concentrated than other cargo handling segments. Ducruet (2013) applied network simplification techniques based on linkage analysis which removes from each port all its links except the largest one. His study revealed that the most diversified ports have a high level of centrality and dominance in the network. They are also connected with more ports situated at a longer physical distance. On the other hand, the most specialized ports capture the majority of global traffic, although their average connection distance is lower due to their distribution role at the intra-regional level.

2.2.2. Maritime and Trade networks in ASEAN+3 community

Since the establishment of ASEAN maritime transport cooperation, ASEAN Member States have been working to promote the progressive liberalization of maritime transport to improve the

region's maritime performance and international competitiveness (ASEAN, 2017). Regarding the development of the ASEAN transport network, Banomyong (2015) applied the Geographical Simulation Model (GSM) to analyze the effects of the implementation of The Master Plan on ASEAN Connectivity (MPAC) by the member states. The study shows that port development is mostly concentrated in specific locations and in countries with better trade facilitation, and that the positive effect it entails could spread to non-ASEAN member states such as Japan, China and India f 89 , p 72 : petit titre en bas de page (CCFI index) which have a better trade facilitation environment. According to the Liner Shipping Index, computed by UNCTAD, the ASEAN community has had steady progress in terms of integration into the global network. However, the index varies across countries and additional efforts are needed to strengthen the maritime connectivity in order to realize the ASEAN Single Shipping Market (ASEAN, 2017). Therefore it is necessary to analyze ASEAN port integration within the regional and global networks, and the relations with ASEAN's closest trade partners: People's Republic of China, Japan, and the Republic of Korea.

There have been a few case studies regarding the countries in the ASEAN+3 community. Sutomo and Soemardjito (2012) applied Multi-criteria Analysis, Analytical Hierarchy Process and Graph Theory to detect the most efficient ports in Indonesia. Their analysis was conducted with a sample of 18 ports with respect of the density of the transportation infrastructure, the capacity of the port, and the speed of goods movement to ports. Zaman et al. (2015) used the Gravity Model to analyze the connectivity of 12 Indonesian ports. By taking into account the ports' facilities, the size of the regional economies, supporting infrastructure (highways, roads, import and export zones, etc.) and connectivity (global, regional and national), the study identified the ports which could play the role of hub under various scenarios. A recent study from Fahmiasari and Parikesit (2017) assessed the efficiency of two plans used for the creation of an integrated container shipping network in Indonesia. They used a few network efficiency indices by taking into account the demand (TEU per year) at the port's origin and destination, ocean freight rates, and the port's connectivity. They concluded that the government should develop the least important ports in the network in order to improve the efficiency of intra-national trade and avoid empty return containers. Lam and Yap (2011) analyzed slot capacity in terms of TEUs – i.e. vessel capacity based on 3000 container shipping services from 1995 to 2006 for the Eastern Asian ports of Shanghai, Ningbo, Busan and Kaohsiung. The study found that inter-container port

complementarity accounted for a significant share of changes to shipping capacity and that the ports periodically restructured their networks to adjust to the demands of the market.

Similar to shipping networks where we see flows of containers between ports of origin and destination, trade flows of goods and services between countries can be represented by directed graphs where all edges are potentially bidirected, as long as exports and imports between two countries are of nonzero values (Nguyen et al., 2016). An analysis of both trade flows and FDI flows within ASEAN+3 countries was recently conducted by Nguyen et al. (2017a). They concluded that during the 1990-2012 period, the degree of trade and FDI integration varied among the ASEAN+3 member states. Furthermore, ASEAN+3's intra-regional trade network seemed to be more densely connected than its intra-regional FDI network, and large or advanced countries tend to be better linked and form a sub-regional bloc of tightly connected economies.

2.2.3. Adding value to the literature

We have not found any studies in the literature comparing the trade and maritime networks. We expect some similarities between the two networks since 90% of exchanged goods are carried via sea (Ducruet, 2013). The position of the ASEAN community within the global shipping network, as well as the connectivity of the designated ASEAN container ports, are topics which also require additional research. Furthermore, most of the studies analysing the importance of various ports use a very limited sample size.

This research adds value to the literature by providing a comprehensive analysis of different types of networks at port and country levels using a sample of 6,410 maritime routes connecting 153 major ports around the world. Since we have almost all the major ports in the ASEAN+3 community, we can conduct an analysis on their intra-regional maritime and trade connectivity. The Network Analysis involves the computation of different centrality measures, allowing us to identify different clusters of tightly linked ports/countries. The method also detects nodes having the highest connectivity, good strategic location, and important intermediate connections. We also identify hub ports, which concentrate most of the maritime traffic or trade of goods between highly connected ports in the network. The findings of this study provide a foundation for understanding

the typology of the global shipping industry, as well as the role of different ports/countries and communities within the network.

2.3. Methodology and data

Network analysis is the process of investigating complex structures through the use of graph theory (Otte and Rousseau, 2002). It has been used in a variety of studies, with the nodes representing individuals, organizations, or even countries, and the ties can refer to communication, cooperation, friendship, or trade. Ties can be differentiated in most settings (Opsahl et al., 2010). Freeman (1978) developed the well-known centrality measures such as Degree, Closeness and Betweenness for binary directed and undirected networks. Degree centrality assesses the number of connections of a node with the other individuals in the network. Closeness centrality shows how easily a node can be reached by other nodes, and betweenness centrality describes how important a node is in terms of connecting other clusters of individuals (Jackson, 2010). These measures have been conceptualized for weighted networks (Newman, 2001, Borgatti, 2005, Brandes, 2001, Barrat et al., 2004, Opsahl et al., 2010).

2.3.1. Network Analysis based on centrality measures in the context of maritime trade

Maritime transport, and containerized trade in particular, consists of carriers transporting goods from port of origin to a given destination. Network analysis has been used by Wang and Cullinane (2016) and Ducruet (2013) to analyze port hierarchy and connectivity. We use directed weighted graphs, where the importance of the flow between the nodes depends on the edges' weights which can be represented by the value of exports, or, the average size of ships multiplied by the number of trips. In this study, the nodes are either a port or a country.

2.3.2. Variables and data

Data on port connectivity was obtained from Lloyd's Marine Intelligence Unit. It contains information about port to port connectivity in 2014, and consists of 153 ports from 51 countries, including 79 ports in Asia, 27 in North America, 20 in Europe, 19 in Africa and 8 in Latin America and the Caribbean. There are 6,410 direct maritime routes connecting the ports in the sample:

- Container port of origin (Source, port i)
- Container port of destination (Target, port j)
- Average size of the ships in TEU going from port i to port j ($AvgTEU_{ij}$)
- Number of trips from port i to port j ($NbTrips_{ij}$)
- Data were also aggregated at a country level in order to analyze the interactions between the states in the sample:
- Country of departure, Source (country a)
- Country of arrival, Target (country b)
- Average size of the ships in TEU going from country a to port b ($AvgTEU_{ab}$)
- Number of trips from port A to port B ($NbTrips_{ab}$)

The export dataset was collected from UN ComTrade⁶¹ commodity databases in the Standard International Trade Classification (SITC) Revision 3. It contains the exports in USD for ASEAN + 3 member states (EXP_{ab}).

2.3.3. Networks

Recall that each maritime route connects a port of origin and a port of destination. In order to analyze the global shipping network as well as the regional networks of the ASEAN+3

⁶¹ <https://comtrade.un.org/>

community, we built five directed weighted networks named the following: ‘Maritime Port Network’, ‘Maritime Country Network’, ‘ASEAN+3 Maritime Port Network’, ‘ASEAN+3 Maritime Country Network’ and ‘ASEAN+3 Export Country Network’.

In the case of maritime networks at port and country levels, the links between each pair of ports/countries are weighted according to the number of trips multiplied by the average size of the vessels operating on a maritime route. This indicator not only shows the frequency of the services (*NbTrips*) but also the relative importance of the container trade flows on the maritime routes *AvgTEU*.

Table 2.1: Type of networks and weighting

Type of network	Type of nodes	No of nodes	No of edges	Weight of edges
Maritime Port Network	Ports	153	6410	$w_{ij} = AvgTEU_{ij} * NbTrips_{ij}$
Maritime Country network	Countries	51	2490	$w_{ab} = AvgTEU_{ab} * NbTrips_{ab}$
ASEAN+3 Maritime Port Network	Ports	68	1745	$w_{ij} = AvgTEU_{ij} * NbTrips_{ij}$
ASEAN+3 Maritime Country Network	Countries	13	135	$w_{ab} = AvgTEU_{ab} * NbTrips_{ab}$
ASEAN+3 Export Country Network	Countries	13	156	$w_{ab} = EXP_{ab}$

Source: Authors' calculations

Table 2.1 depicts some basic features of the networks at port and at country levels. In the maritime network ‘ASEAN+3 Export Country Network’, the edges are weighted according to the value of exports in USD (*EXP*). This indicator allows us to assess the importance of the trade between countries for all goods. Appendix 2.A shows additional descriptive statistics about the variables that we used in this study.

2.3.4. Centrality measures used in this study

In order to analyze the different types of networks, and the hierarchy of ports or countries within them, we have computed a set of centrality measures for weighted directed graphs. The weight of the edges are according to the type of network and nodes (Table 2.1).

2.3.4.1. Weighted degree Centralities

In the case of directed graphs, there are two types of degree centralities, Indegree and Outdegree. The former shows the sum of all edges that are directed (pointing in) to node i while the latter depicts all edges that are going out from the node i . Mathematically, both measures can be represented by equations 1 and 2.

$$ws_i^{out} = \sum_j^N w_{ij} \quad (1) \quad ws_i^{in} = \sum_j^N w_{ji} \quad (2)$$

ws_i^{out} and ws_i^{in} refers to the weighted Outdegree and Indegree centralities of node i , which are the sum of the weights of the edges w_{ij} of all nodes N which have a direct incoming or outgoing connection with node i . Nodes i and j are connected when $w_{ij} > 0$. Ports having many connections with others and accommodating large ships have high Indegree coefficients, while ports which are a point of departure of a considerable number of vessels have high Outdegree scores. The same logic applies to the analysis of the interaction at a country level as well as in the case of the countries' exports where the weights of the edges are according to the value of exported goods.

2.3.4.2. Weighted Betweenness and Closeness Centralities

Betweenness and closeness centralities in weighted networks are based on the Dijkstra's algorithm (Dijkstra, 1959). The Newman (2001) and Brandes (2001) algorithm to estimate the shortest path between two nodes in a weighted network is as follows:

$$d^w(i, j) = \min \left(\frac{1}{w_{ih}} + \dots + \frac{1}{x_{hj}} \right) \quad (4)$$

$d^w(i, j)$ refers to the weighted distance between node i and node j , while h is an intermediate node situated on the shortest path between i and j . Therefore, weighted closeness centrality of node i (wC_i) can be depicted by equation 5.

$$wC_i = \left[\sum_j^N d^w(i, j) \right] \quad (5)$$

In the context of containerized trade, a port with high weighed closeness centrality refers to a port with the possibility of reaching all other ports in the network by passing through not so many intermediate nodes.

Weighted Betweenness centrality (wB_i) is based on a combination of the number of intermediary nodes and tie weights (Opsahl et al., 2010). It can be represented by the following equation:

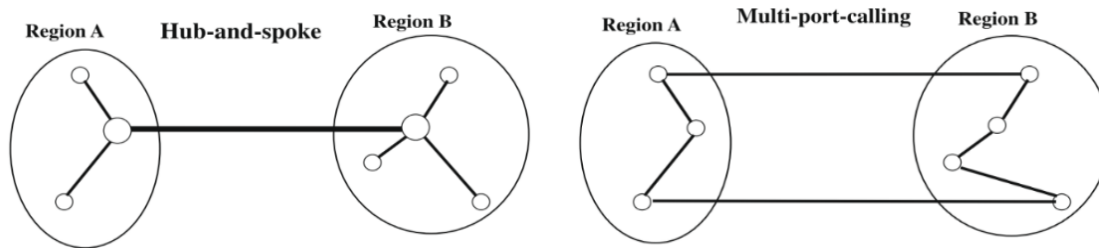
$$wB_i = \frac{b_{jk}^w(i)}{b_{jk}^w} \quad (6)$$

$b_{jk}^w(i)$ refers to the number of times that node i is an intermediate passage for node j to reach all k nodes in the network, as well as the associated weights to the links. Ports with high weighted betweenness have a strategic position in the network, and might play a role as an important hub port or an obligatory passage to reach other ports.

2.3.4.3. Hub Coefficient

There are two main types of network configurations in the maritime trade: the hub and spoke network and the multi-port network (Figure 2.1). The first one is a system of connections where all traffic moves along spokes connected to the hub at the centre. By contrast, the multi-port calling configuration is characterized by direct trajectories of any given vessel between the ports. Such structure is used in the case of relatively small container port networks.

Figure 2.1: Hub and Spoke versus Multi-Port Calling configuration



Source: (Imai et al., 2009)

We used the algorithm of Kleinberg (1999) to detect hub ports, which was applied in the context of online queries and analysis of the hyperlink structure among ‘www’ pages. This algorithm identifies authoritative ‘www’ pages (authorities) for broad search topics. Pages that connect a number of authorities are called hubs.

Regarding maritime transport, ports having high Hub coefficients are connected to ports with high Indegree centrality. This algorithm allows us to identify ports which are mainly connected to other major ports in the network.

2.3.4.4. Identification of clusters

A related question of interest is to know if one port belongs to a particular community of ports, and if yes, how this community is defined? As stated by Pons (2005) and Pons and Latapy (2006), the concept of community in graph theory is not clearly defined. However, it is possible to define a community as a set of vertices (nodes) where the density of internal connections is greater than the density of connections to the outside (Pons, 2005). Accordingly, to calculate the potential communities within a given network, one should split the network into a given number of groups. In order to determine different groups of ports or countries, we use the modularity algorithm for weighted direct networks applied by Blondel et al. (2008).

In summary, by applying Network Analysis and Graph Theory we can identify the ports/countries (i) with the most outgoing and incoming connections (degree centrality), (ii) which have diverse connections and are easily reachable by other nodes in the network (closeness centrality), (iii) which are intermediate links ‘bridges’ connecting different clusters or peripheral nodes (betweenness centrality) and (iv) which play the role of hub in regional and global shipping networks. In addition, this methodology allows us to discern tightly connected clusters of ports/countries.

2.4. Results

The networks analyses were conducted using Gephi software (version 0.9.2) and R software (Package ‘tnet’⁶²).

2.4.1. Maritime Port Network (153 nodes)

2.4.1.1. Typology of the global “Maritime Port Network”

As shown in Appendix 2.A, the descriptive statistics of the nodes and the link attributes reveal a significant dispersion around the mean, as the studied sample consists of highly heterogeneous ports and maritime routes. The network has a high degree of connectivity (Table 2.2). On average, the bivariate distance between any two connected nodes is 1.809 edges and each interacts with approximately 48 other ports in the sample.

⁶² <https://cran.r-project.org/web/packages/tnet/tnet.pdf>

Table 2.2: Characteristics of the Maritime Port Network

Clustering Coefficient	0.695
Diameter	4
Average Path Length	1.809
Average bivariate Degree	47.81699346
Average Weighted degree	16,409,626.386
Node Count	153
Density	0.276

Source: Authors' calculations

The clustering coefficient reflects the probability of being connected to other nodes in the network. It is relatively significant (0.69), as should be expected, considering the average number of neighbours of each node. It is also observed that the network density is small (0.276). The Graph Density measures how complete the network is (Bastian et al., 2009). A complete network contains all possible edges and has a density of 1.

These results indicate that the network has a scale-free configuration. Such networks, introduced by Barabási and Albert (1999), are mainly characterized by a degree of distribution that follows a power law, with a few highly-connected nodes and a majority of nodes with lower degrees of centralities.

2.4.1.2. Ranking of the ports in the Global Maritime network based on the centrality measures

When we look at the rankings of the 153 ports in the 'Maritime Port Network' (Appendix 2.B), we observe that ports change their position according to different centrality measures. Recall that the weight of the links between the ports is according to the Number of Trips multiplied by the average size of the vessels operating between each pair of ports.

Table 2.3 depicts the top 20 ports ranked in terms of the selected network indicators. The most important port in Europe is the port of Rotterdam, as it has the highest Outdegree score. This

means that the frequency and the size of the ships departing from this port of origin are substantial. In terms of Indegree centrality, Singapore has the highest score and Rotterdam ranks second.

Table 2.3: Ranking of top 20 ports according to different centrality measures

No	Rank Outdegree (weighted)	Rank Indegree (weighted)	Rank Closeness (weighted)	Rank Betweenness (weighted)	Rank Hub
1	Rotterdam	Singapore	Port Said	Singapore	Singapore
2	Singapore	Rotterdam	Singapore	Port Said	Hong Kong
3	Shanghai	Port Said	Shanghai	Shanghai	Ningbo-Zhoushan
4	Hong Kong	Shanghai	Rotterdam	Rotterdam	Shanghai
5	Ningbo-Zhoushan	Hong Kong	Ningbo-Zhoushan	Hong Kong	Shenzhen
6	Port Said	Antwerp	Hamburg	Balboa	Port Klang
7	Hamburg	Hamburg	Hong Kong	Valencia	Rotterdam
8	Shenzhen	Ningbo-Zhoushan	Shenzhen	New York	Tanjung Pelepas
9	Antwerp	Bremen/Bremerhaven	Antwerp	Tokyo	Kaohsiung
10	Bremen/Bremerhaven	Shenzhen	Bremen/Bremerhaven	Belawan	Port Said
11	Tokyo	Le Havre	Valencia	Port Klang	Hamburg
12	Le Havre	Valencia	Felixstowe	Marsaxlokk	Antwerp
13	Valencia	Tokyo	Yokohama	Tanjung Priok (Jakarta)	Algeciras
14	Felixstowe	Yokohama	Tokyo	Antwerp	Jebel Ali (Dubai)
15	Yokohama	New York	Algeciras	Yokohama	Le Havre
16	New York	Felixstowe	Tanjung Pelepas	Tanjung Perak (Surabaya)	Valencia
17	Algeciras	Nagoya	Port Klang	Shenzhen	New York
18	Nagoya	Algeciras	Le Havre	Ningbo-Zhoushan	Norfolk (USA)
19	Kaohsiung	Jebel Ali (Dubai)	Southampton	Port Everglades	Balboa
20	Port Klang	Kaohsiung	Keelung	Algeciras	Bremen/Bremerhaven

Source: Authors' calculations

Although Port Said had an annual throughput of only 3.96 million TEU in 2014, it has the highest closeness coefficient due to its unique geographical location. The port is located at the

north gate of the Suez Canal, a 200 km-long canal that connects the Mediterranean with the Red Sea (El-bastawisy and Abd-al-whab Helmy, 2006), and is at a strategic position easily reachable by many ports in the sample. Singapore is ranked second due to its role as a major hub port connecting Southeast Asia with Western Asia, Europe and Africa. Similar to the findings of Wang and Cullinane (2016), the Chinese ports of Shanghai, Shenzhen and Hong Kong have very high weighted closeness scores and rank 3rd, 7th and 8th respectively. Ningbo-Zhoushan is another Chinese container port which is ranked 5th and is situated in the Yangtze River Delta, a large industrial and logistics area.

Similar to closeness centrality, the betweenness measures show that the ports serving as the most important intermediate passages are Singapore, Port Said and Shanghai. It is interesting to highlight that the port of Balboa is in 6th place. It is an important hub connecting Far East and North America to the West Coast of South America, Central America and the Caribbean. Like Port Said in Egypt, the Panamanian port has a strategic location on the Panama Canal which makes it a compulsory intermediate node for the majority of traffic in Latin and Central America. Although weighted betweenness centrality identifies major hubs of the global network, Belawan with an annual throughput of 600,000 TEUs is ranked 10th. This means that the port is not a hub, but is compulsory passage for many smaller regional ports (feeder ports). Other Indonesian ports such as Port Klang, Tanjung Priok and Tanjung Perak (Surabaya) also play a key role in connecting the ASEAN community to the global shipping network.

In order to detect major hub ports in the global ‘Maritime Port Network’ we look at the Hub Coefficient. Unsurprisingly, the most important hub ports are identified as Singapore, Hong Kong, Ningbo-Zhoushan, Shanghai, Shenzhen, Port Klang and Rotterdam. These ports have very strong links between them as well as with other major ports in the network.

When we look at the correlation coefficients of the centrality measures and the annual throughput in 2014 (Table 2.4), there is very strong correlation between Outdegree and Indegree centralities (0.99). It means that ports which are major points of departure for many ships are also major destinations. In addition, indegree and outdegree are both positively correlated to Hub, Betweenness and Container Throughput. Thus, ports with high hub coefficients are intermediate links with a capacity to handle many containers and, due to their geographical locations, are easily reachable by other ports in the network.

Table 2.4: Correlation matrix between weighted centrality measures for the Maritime Port Network

	Outdegree	Indegree	Closeness	Betweenness	Hub	Container Throughput
Outdegree	1					
Indegree	0.99	1				
Closeness	0.34	0.35	1			
Betweenness	0.74	0.74	0.18	1		
Hub	0.80	0.81	0.61	0.47	1	
Container Throughput	0.72	0.68	0.22	0.63	0.62	1

Source: Authors' calculations

The existence of hub ports in the 'Maritime Port Network' reveals that any dysfunction or removal of one hub can lead to the separation of different clusters or communities, and to a larger extent, the destabilization of the logistics chain (Xu et al., 2015).

Appendix 2.C shows a graphical representation of the Maritime Port Network where we see that five communities have been identified. The first community consists of ports belonging to eleven countries from North and South America (see last column of the table in Appendix 2.B). In the second cluster there are 10 European, 1 Canadian and 1 Moroccan ports. The third community is formed by 51 ports from Europe, Asia, the Middle East and Africa. The fourth group of closely connected ports is dominated by ports from China, Taiwan, the U.S. and the Philippines. In this group we also have a few ports from Mexico. The last community only contains ports from Indonesia. These results reveal that the geographical location of a port is not enough by itself to explain the connections with other ports.

2.4.2. Maritime Country Network

At a country level, the maritime network is a polarized or scale-free structure with a high level of connectivity. It is a core-periphery structure where the most important countries are the world's main importers and exporters. Japan, Egypt and Spain have very high closeness

coefficients, which means that they have strategic locations in the network. In terms of intermediate nodes, Spain, Japan, Germany and Malaysia are found to be the most important nodes. We have not estimated the hub coefficient due to the high level of density of the network and the fact that almost all countries in the sample are interconnected.

Table 2.5: Characteristics of the Maritime Country Network

Clustering Coefficient	0.792
Diameter	3
Average Path Length	1.408
Average Bivariate Degree	29.784
Average Weighted degree	42,509,324.093
Node Count	51
Graph Density	0.596

Source: Authors' calculations

Unsurprisingly, at the country level the clustering coefficient and the graph density are higher than in the Maritime Port Network (Table 2.5).

When we compare the countries in the sample, we observe that China and the U.S. are the most connected nodes according to all centrality measures (Table 2.6). In terms of Indegree and Outdegree centralities, Germany has the highest connectivity in Europe, followed by Spain and the Netherlands.

Table 2.6: Ranking of top 10 countries according to different centrality measures

	Outdegree	Ranking Indegree (weighed)	Ranking closeness (weighted)	Ranking betweenness (weighted)
1	China	China	China	China
2	USA	USA	USA	USA
3	Germany	Germany	Japan	Spain
4	Singapore	Spain	Egypt	Japan
5	Netherlands	Singapore	Spain	Germany
6	Spain	Belgium	Germany	Malaysia
7	Japan	Netherlands	Hong Kong	Singapore
8	Hong Kong	Japan	Singapore	Egypt
9	Belgium	Egypt	Netherlands	Belgium
10	Egypt	Hong Kong	Taiwan	Taiwan

Source: Authors' calculations

We have identified four clusters of tightly connected countries. (see the last column of the table in Appendix 2.D). The first one is constituted by only European countries. The second cluster includes 21 nodes mainly from Asia and the Middle East. The third cluster is the most diverse with countries from Europe, Asia, South America and Africa. Finally, similar to the port network, North and South American countries form a community.

2.4.3. ASEAN+3 Maritime Port Network

In this section we analyze the ports belonging to the ASEAN+3 community, which includes China, Hong Kong, Taiwan, South Korea, Japan, Singapore, Thailand, Vietnam, Indonesia, Malaysia, Cambodia, the Philippines and Brunei. We did not include Myanmar due to the lack of data, and we did not include Laos since it is a land locked country.

Table 2.7: Characteristics of the ASEAN+3 Maritime Port Network

Clustering Coefficient	0.741
Diameter	4
Average Path Length	1.677
Average Bivariate Degree	25.662
Average Weighted degree	7,332,918
Node Count	68
Graph Density	0.383

Source: Authors' calculations

The low graph density (0.383) and the average path length of 1.677 suggest that the ports are well connected and that on average they interact with 25.7 nodes in the sample (Table 2.7). The good connectivity between the ASEAN+3 ports is confirmed by the high clustering coefficient (0.741).

In contrast with the global 'Maritime Port Network', within 'The ASEAN+3 Ports Network' Singapore is ranked 5th and 7th in terms of Outdegree and indegree respectively. In terms of intra-ASEAN outgoing and incoming traffic, the Japanese ports and Honk Kong are the most important ones (Table 2.8). However, Singapore is the gateway port of ASEAN+3 to the global shipping market. It has many direct connections with smaller (feeder) ports and its role as a major transshipment centre for Eastern and South-Eastern Asia is confirmed by its high closeness and betweenness coefficients. Shanghai, Hong Kong and Shenzhen are also important intermediate ports. The high hub coefficients of Hong Kong, Singapore, Shanghai, Shenzhen and Kaohsiung show that these ports are mainly connected with other hubs of the 'ASEAN+3 Maritime Port Network'. Appendix 2.F shows detailed centrality measures for all ports in the sample.

Table 2.8: Ranking of top 20 ASEAN+3 ports according to different centrality measures

	Outdegree	Indegree	Closeness	Betweenness	Hub
1	Tokyo	Tokyo	Singapore	Singapore	Hong Kong
2	Yokohama	Yokohama	Tokyo	Shanghai	Singapore
3	Nagoya	Nagoya	Yokohama	Hong Kong	Shanghai
4	Hong Kong	Hong Kong	Hong Kong	Shenzhen	Shenzhen
5	Singapore	Shenzhen	Shenzhen	Tokyo	Kaohsiung
6	Shenzhen	Shanghai	Shanghai	Yokohama	Port Klang
7	Shanghai	Singapore	Nagoya	Tanjung Priok (Jakarta)	Ningbo-Zhoushan
8	Keelung	Ningbo-Zhoushan	Ningbo-Zhoushan	Port Klang	Nagoya
9	Ningbo-Zhoushan	Keelung	Keelung	Tanjung Perak (Surabaya)	Laem Chabang
10	Kaohsiung	Kaohsiung	Hanshin Ports	Belawan	Tanjung Priok (Jakarta)
11	Hanshin Ports	Hanshin Ports	Kaohsiung	Bangkok	Hanshin Ports
12	Bangkok	Bangkok	Penang	Manila	Tokyo
13	Port Klang	Busan	Port Klang	Ningbo-Zhoushan	Yokohama
14	Laem Chabang	Port Klang	Bangkok	Kota Kinabalu	Penang
15	Busan	Laem Chabang	Laem Chabang	Kaohsiung	Tanjung Pelepas
16	Penang	Tanjung Pelepas	Busan	Tanjung Mas (Semarang)	Xiamen
17	Lianyungang	Penang	Belawan	Laem Chabang	Busan
18	Xiamen	Lianyungang	Lianyungang	Zhanjiang	Manila
19	Tanjung Priok (Jakarta)	Xiamen	Xiamen	Ho Chi Minh City	Keelung
20	Tokyo	Tanjung Priok (Jakarta)	Tanjung Mas (Semarang)	Nantong	Bangkok

Source: Authors' calculations

The correlation matrix between the centrality measures of the 'ASEAN+3 Maritime Port Network' is similar to that of the maritime port network. However, it should be noted that the correlation between Outdegree and hub, as well as indegree and hub, is lower in this network with 0.68 and 0.69 respectively. This is normal since we observe a regional network of well interconnected ports.

Table 2.9: Correlation matrix between weighted centrality measures for “the ASEAN+3 Maritime Port Network”

	Outdegree	Indegree	Closeness	Betweenness	Hub	Container Throughput
Outdegree	1					
Indegree	0.9971	1				
Closeness	0.3418	0.3446	1			
Betweenness	0.7032	0.7	0.2583	1		
Hub	0.6798	0.6875	0.6614	0.5346	1	
Container Throughput	0.5678	0.5839	0.2286	0.7652	0.57	1

Source: Authors' calculations

Container throughput is highly correlated with betweenness centrality. Therefore, ports with high betweenness in the ASEAN+3 network also constitute an important part of the intra-ASEAN+3 maritime traffic.

As we can see in Appendix 2.G, three communities have been identified in this network. The first one includes 8 ports from Japan, Korea, and China. The second one includes 29 ports exclusively from ASEAN. The only ASEAN country we studied which does not have any ports in this cluster is the Philippines. The last cluster is the biggest one and has 31 ports from China, Hong Kong, Taiwan and the Philippines. These results suggest that the ASEAN ports have a strong maritime intra-regional integration. As a corollary, it means that the ASEAN Single Shipping Market and its designated ports maintain close ties. In addition, there is also a high level of connectivity between Chinese ports and Hong Kong.

2.4.4. Comparison between ASEAN+3 Maritime Country Network and ASEAN+3 Export Country Network

Since the dataset includes almost all major ports situated in ASEAN+3 nations, we focus our analysis on the particular case of the maritime and export networks at a country level in this community. Recall that in the former network weights of edges are based on the Number of Trips

multiplied by the average size of the containerships in TEUs, while in the latter, weights correspond to country Exports in USD.

Table 2.10: Characteristics of ASEAN+3 Maritime Country Network and ASEAN+3 Export Country Networks

	ASEAN+3 Maritime Country Network	ASEAN+3 Export Country Network
Clustering Coefficient	0.909	1
Diameter	2	1
Average Path Length	1.135	1
Average Bivariate Degree	10.385	12
Average Weighted degree	25,181,747	224,695,259
Node Count	13	13
Graph Density	0.865	1

Source: Authors' calculations

Unsurprisingly, the 'Export Country Network' is denser, since it takes into account all exported goods. On the other hand, ASEAN+3 countries have 10.38 maritime country connections on average.

At first glance we can see that major economies such as China, Japan and Hong Kong, which act as bridges toward Europe and North America, play a substantial role in both networks (Table 2.11). In the case of the ASEAN+3 Maritime Country Network, we have identified two clusters. The first one includes all ASEAN states except the Philippines, while the second is constituted of China, Philippines, Japan, South Korea, Hong Kong and Taiwan. It confirms our previous finding that ASEAN countries form a well-connected community where the dominant port is Singapore (being both a port and a country).

Table 2.11: Rankings of the ASEAN+3 countries in the Export and Maritime Network according to different weighted centrality measures

	ASEAN+3 Maritime Country Network				ASEAN+3 Export Country Network			
Node	Outdegree	Indegree	Closeness	Betweenness	outdegree	Indegree	Closeness	Betweenness
Brunei	12	12	12	6	13	12	13	5
Cambodia	13	13	13	6	12	13	11	5
China	2	2	2	5	1	1	1	1
Hong Kong	3	3	4	6	2	2	3	5
Indonesia	9	9	9	6	9	9	9	5
Japan	1	1	1	1	3	3	2	2
Malaysia	6	6	6	2	6	7	7	5
Philippines	10	10	10	6	11	11	12	5
Singapore	5	5	3	3	5	5	6	3
South Korea	8	8	8	6	4	4	4	5
Taiwan	4	4	5	4	7	6	8	5
Thailand	7	7	7	6	10	8	10	4
Vietnam	11	11	11	6	8	10	5	5

Source: Authors' calculations

Regarding the Export Country Network (Appendix 2.K), we have identified two clusters of countries. The most dominant nodes are China and Hong Kong, and they form the first community. These results are consistent with the outcomes of the modularity analysis of the third network, 'ASEAN+3 Port Network', where Chinese ports and Hong Kong form the third cluster. The other states belong to the second community which is dominated by Japan and South Korea.

In both observed networks Japan, China and Hong Kong have the highest scores. In addition, the rankings of Cambodia, Brunei, Philippines and Thailand are very similar. Vietnam has low Outdegree and Indegree centralities while its betweenness scores are higher in the two networks. It should be highlighted that in the Maritime as well as the Export network, Singapore plays an important role as a bridging organization (high betweenness centrality). These results suggest that in the context of ASEAN+3, the development of the port infrastructure and the connectivity has a

substantial impact on the overall trade performance. When we look at the structure of the Trade and Maritime Networks of ASEAN+3, we observe similar features not only at the country level but also at port level.

2.5. Conclusion

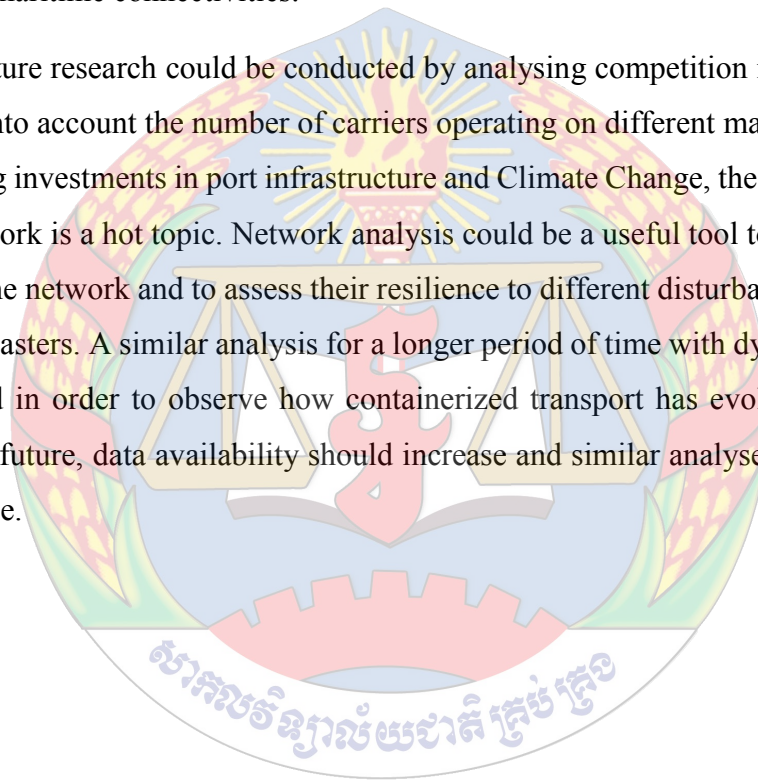
Network Analysis is a suitable method to investigate the structure of the maritime transport system as well as the hierarchy of the ports/countries at global and regional levels according to different centrality measures. We have analyzed five types of directed weighted networks. The weights of the links between nodes are according to the number of trips and the size of the containership vessels operating between the origin and destination ports, or, the value of countries' exports.

The first network consists of 153 ports from all around the world. Our findings confirm the hub and spoke structure of the Global Maritime Network. As major hubs have been identified Singapore, Hong Kong, Ningbo-Zhoushan, Shanghai and Shenzhen. Ports with relatively low Indegree and Outdegree centralities, such as Port Said, Balboa and Belawan, have very high betweenness centralities which indicates their strategic geographical position and connections with ports which are situated at the periphery of the global network. When we aggregate the data at the country level, the 'Maritime Country Network' shows a similar pattern. The European states as well as North and South America form linked communities. China, the U.S., the Netherlands, and Japan are intermediate passages.

We have also analyzed the intra-maritime connectivity between ports situated in the ASEAN+3 countries. The Japanese ports and Hong Kong play the most important roles in terms of outgoing and incoming traffic. However, Shanghai and Singapore are found to have the highest betweenness scores which make them important intermediate points connecting many ports in the network. Furthermore, modularity analysis identifies a community of ports from exclusively ASEAN member states except the Philippines. This finding reveals that ASEAN states had a good intra-regional connectivity in 2014.

A comparative analysis was conducted between the maritime and trade integration of ASEAN+3 countries. In the case of maritime connectivity, all ASEAN member states form the first cluster, while China, Taiwan, Hong Kong, Republic of Korea and Japan are associated with the second cluster. When we weight the links between countries according to the exports, the 'ASEAN+3 Export Country Network' has similar features as the 'ASEAN+3 Maritime Country Network', even though the rankings for some countries was slightly different. Similar to the Ports Network, China and Hong Kong form one community, while Singapore plays an important intermediate role in both networks. These findings confirm the comparable pattern of countries' exports and their maritime connectivities.

Potential future research could be conducted by analysing competition in the liner shipping sector by taking into account the number of carriers operating on different maritime routes. In the context of ongoing investments in port infrastructure and Climate Change, the sustainability of the supply chain network is a hot topic. Network analysis could be a useful tool to detect ports which are important in the network and to assess their resilience to different disturbances such as natural and man-made disasters. A similar analysis for a longer period of time with dynamic graphs could be also conducted in order to observe how containerized transport has evolved throughout the years. In the near future, data availability should increase and similar analyses might be possible for a bigger sample.



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2.7. Appendices

2.A. Descriptive statistics of different type of networks

Type of network	Nodes	Edges	Variables	Mean	Std. Dev.	Min	Max
Maritime Port Network	153	6410	AvgTEU	4299.762	3015.468	80	18270
			NoTrips	99.69938	277.1175	1	5510
Maritime Country network	51	1,519	AvgTEU	4911.418	2861.2	142	18270
			NoTrips	328.6866	912.2704	1	16872
ASEAN+3 Maritime Port Network	68	1745	AvgTEU	2022.986	1574.131	80	14080
			NoTrips	144.4292	412.3873	1	5510
ASEAN+3 Maritime Country Network	13	135	AvgTEU	1797.992	1205.591	608	6191
			NoTrips	1002.66	2233.5	1	16872
ASEAN+3 Export Country Network	13	156	Exports in '000 USD	1.87E+07	4.32E+07	39.708	3.63E+08

Source: Authors' calculations

2.B. Main weighted centralities measures for the “Maritime Port Network”

Weighted centrality measures for the “Maritime Port Network” as well as the modularity class to which every port belongs.

Port	Country	Throughput '000 TEUs	Outdegree	Indegree	Closeness	Betweenness	Hub	Modularity Class
Singapore	Singapore	33900	118149	117755	0.0002553	8203	0.160737	2
Hong Kong	Hong Kong	22300	100390	89205	0.0002549	3860	0.160206	3
Ningbo-Zhoushan	China	19500	95592	76385	0.000255	823	0.159628	3
Shanghai	China	35300	111663	92816	0.0002551	6105	0.159469	3
Shenzhen	China	24037	77508	63956	0.0002549	956	0.155226	3
Port Klang	Malaysia	10946	44367	40504	0.0002544	1241	0.14527	2
Rotterdam	Netherlands	12298	120562	116484	0.0002551	4417	0.143447	1
Tanjung Pelepas	Malaysia	8232	39650	28106	0.0002545	306	0.137985	2
Kaohsiung	Taiwan	10593	44712	44255	0.0002537	450	0.137476	3
Port Said	Egypt	3959	90325	99082	0.0002553	8093	0.13576	2
Hamburg	Germany	9775	86048	83600	0.000255	283	0.135682	1
Antwerp	Belgium	8812	76157	85000	0.0002547	1134	0.135152	1
Algeciras	Spain	4555	46702	44956	0.0002545	749	0.134779	2
Jebel Ali (Dubai)	United Arab Emirates	15249	25922	44475	0.0002538	262	0.133776	2
Le Havre	France	2433	56095	62756	0.0002544	0	0.132202	1
Valencia	Spain	4442	55294	61160	0.0002546	1864	0.131433	2
New York	United States of America	5772	51713	50009	0.0002539	1729	0.131198	0
Norfolk (USA)	United States of America	2393	38504	43175	0.0002539	531	0.130281	0
Balboa	Panama	3468	36170	41370	0.0002539	1996	0.129293	0
Bremen/Bremerhaven	Germany	5731	64158	64553	0.0002547	549	0.128586	1
Hanshin Ports	Japan	2049	27443	31177	0.0002539	185	0.120247	3

Tangier-Mediterranee	Morocco	3070	37267	36626	0.000253 7	274	0.12012 3	2
Felixstowe	United Kingdom	4072	52585	49102	0.000254 6	164	0.11964 2	1
Barcelona	Spain	1893	34409	37668	0.000254 3	373	0.11893 4	2
Genoa	Italy	2014	29392	30303	0.000254 2	130	0.11712 1	2
La Spezia	Italy	1262	23890	22454	0.000253 5	0	0.11494 9	2
Yokohama	Japan	2880	52289	50985	0.000254 6	1091	0.11395 7	3
Busan	South Korea	18700	15141	16012	0.000252 3	2	0.11349 3	3
Charleston	United States of America	1792	25453	27114	0.000252 7	444	0.11310 9	0
Colombo	Sri Lanka	4908	7170	8296	0.000249	302	0.11122 5	2
Nagoya	Japan	2569	46574	46271	0.000254 2	147	0.10882 1	3
Tokyo	Japan	4894	58732	56035	0.000254 5	1493	0.10866 2	3
Jawaharlal Nehru	India	4467	18054	16653	0.000252 7	151	0.10766 3	2
Qingdao	China	16660	2356	1837	0.000244 4	0	0.10644 5	3
Durban	South Africa	2644	16968	17701	0.000253 9	0	0.10609 9	2
Oakland	United States of America	2394	33909	36491	0.000254 2	267	0.10514 3	3
Laem Chabang	Thailand	6583	14955	13708	0.000252 5	311	0.10484 8	3
Southampton	United Kingdom	1894	31915	34905	0.000254 3	0	0.10274 1	1
Marsaxlokk	Malta	2869	27905	28793	0.000254 1	1196	0.10182 3	2
Kingston(JAM)	Jamaica	1638	10960	12271	0.000251 1	0	0.10098 4	0
Sines	Portugal	1228	20466	21944	0.000252 4	0	0.10080 6	1
Houston	United States of America	1951	16012	16519	0.000251 3	146	0.09983 3	0
Salalah	Oman	3000	18014	17289	0.000253 1	0	0.09815 1	2
Zeebrugge	Belgium	2047	20222	22386	0.000253 4	0	0.09733	2
Baltimore	United States of America	779	10009	10970	0.000251 1	151	0.09719 2	0
Manzanillo (MEX)	Mexico	2355	17426	19414	0.000253 3	5	0.09689 4	3
Xiamen	China	8600	11107	9573	0.000251 5	0	0.09674 9	3
Gioia Tauro	Italy	3708	22955	24927	0.000253 4	151	0.09648 3	2

Santos	Brazil	3685	38882	43005	0.000254 2	561	0.09614 2	0
Long Beach	United States of America	6817	20971	20111	0.000254	154	0.09601 8	3
Seattle/Tacoma	United States of America	3616	25629	24840	0.000253 9	115	0.09134 3	3
Djibouti	Djibouti	736	10038	11075	0.000252 1	0	0.08743 7	2
Miami	United States of America	877	8732	9619	0.000249 3	0	0.08697 3	0
Jeddah	Saudi Arabia	4218	11088	15221	0.000252 6	0	0.08595 4	2
Chennai	India	1552	3112	2750	0.000250 2	0	0.08423 3	2
Halifax	Canada	400	8196	7880	0.000251 3	0	0.08230 8	0
Jacksonville	United States of America	937	8132	9325	0.000249 3	4	0.08144 1	0
Keelung	Taiwan	1686	28954	26053	0.000254 3	236	0.08043 7	3
Abidjan	Ivory Coast	600	5053	4741	0.000250 2	0	0.07987 2	2
Weihai	China	650	3148	3126	0.000242 2	0	0.07915 8	3
Los Angeles	United States of America	8340	17781	16221	0.000253 3	0	0.07824 6	3
Dalian	China	10128	938	674	0.000228 6	0	0.07807 4	3
Buenos Aires	Argentina	1429	17610	21395	0.000253 4	0	0.07716 9	0
Lianyungang	China	5005	9610	8830	0.000251 9	22	0.07702	3
Freeport (BHS)	Bahamas	1400	6427	8069	0.000245	0	0.07549 2	0
Manila	Philippines	3673	4628	4377	0.000247 8	608	0.07450 3	3
Port Everglades	United States of America	1013	9927	10293	0.000249 4	783	0.07394 3	0
Khor Fakkan	United Arab Emirates	3800	11116	11501	0.000252 3	0	0.07381 2	2
Buenaventura	Colombia	855	7587	10541	0.000252 3	0	0.07349 4	0
Yantai	China	2361	5269	5350	0.000248 4	0	0.07309 9	3
Tanjung Priok (Jakarta)	Indonesia	6053	7121	7009	0.000249 1	1178	0.07012 2	4
Algiers	Algeria	857	2720	2778	0.000248 4	302	0.06924 6	2
Vancouver (CAN)	Canada	2913	11515	12198	0.000252 7	0	0.06873 1	3
Shantou-Jieyang	China	1199	2294	2233	0.000247 5	0	0.06789 1	3

Bejaia	Algeria	190	1246	1203	0.000238 5	0	0.06585 6	2
Veracruz	Mexico	847	11508	11045	0.000250 6	116	0.06437 9	0
Wenzhou	China	604	1093	1111	0.000238 6	0	0.06404 6	3
Mobile	United States of America	237	5247	5620	0.000247 8	0	0.06370 8	0
Lagos	Nigeria	1600	3015	4571	0.000249 1	0	0.06285 4	2
Penang	Malaysia	1266	9563	9529	0.000254	0	0.06222 7	2
Jiangyin	China	1000	569	269	0.000236 9	0	0.06085 9	3
San Antonio (CHL)	Chile	1094	6523	8342	0.00025	0	0.05919 4	0
Boston (USA)	United States of America	214	4787	4689	0.000249 2	0	0.05828 2	0
Bangkok	Thailand	1536	13202	12600	0.000253 2	743	0.05787 7	3
Philadelphia	United States of America	449	5566	4833	0.000247 7	0	0.05588	0
Savannah	United States of America	3136	184	224	0.000158 6	0	0.05585 7	0
St. Petersburg	Russia	2375	10036	10080	0.000253 5	0	0.05567 5	1
Keihin Ports	Japan	#N/A	4045	3691	0.000249 7	0	0.05485 5	3
Puerto Limon	Costa Rica	1090	1398	1775	0.000234 9	0	0.05244 3	0
Tanjung Perak (Surabaya)	Indonesia	3128	3571	4453	0.000244 1	1036	0.05082 2	4
San Francisco	United States of America	N/A	436	529	0.000200 1	0	0.04968 8	3
Nantong	China	550	509	285	0.00023	302	0.04960 5	3
Casablanca	Morocco	846	5534	5574	0.000249 8	151	0.04955 8	2
Marseilles/Fos	France	1190	1851	1857	0.000243 7	0	0.04887	2
Arzew	Algeria	0	160	194	0.000170 8	0	0.04768 9	2
Batangas	Philippines	135	1234	1238	0.000236 6	0	0.04730 7	3
Fangchenggang	China	N/A	1736	1722	0.000248 6	0	0.04570 9	3
Skikda	Algeria	148	827	850	0.000233 9	0	0.04480 4	2
Belawan	Indonesia	600	4295	4341	0.000251 9	1285	0.04367 9	4
Annaba	Algeria	N/A	286	293	0.000213	0	0.04333 2	2
Qinhuangdao	China	414	1034	1018	0.000235 6	0	0.04327 7	3

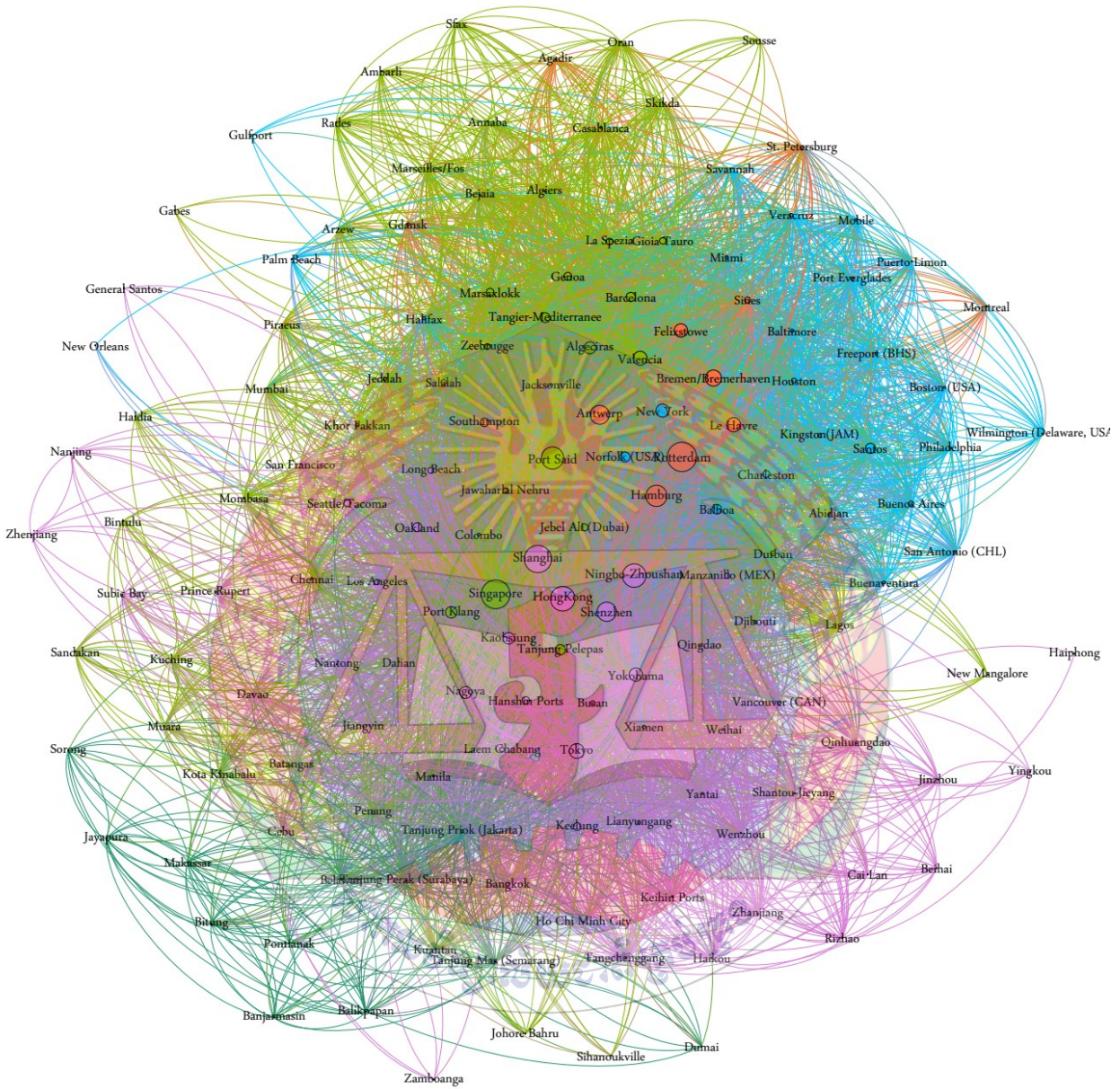
Davao	Philippines	612	1863	1757	0.000242 6	148	0.04197 3	3
Kuantan	Malaysia	131	1826	1809	0.000249	0	0.04170 1	2
Mumbai	India	40	167	233	0.000165 7	0	0.04136 3	2
Gdansk	Poland	1232	9378	10841	0.000253 2	0	0.04125 9	1
Tanjung Mas (Semarang)	Indonesia	576	3979	3996	0.000250 9	429	0.04122 3	4
Zhanjiang	China	581	2442	2451	0.000247 6	302	0.04084 4	3
Haikou	China	1347	474	467	0.000219 6	0	0.04076 3	3
Ho Chi Minh City	Vietnam	6515	982	895	0.000238 8	302	0.03780 4	3
Piraeus	Greece	3585	238	284	0.000187 5	0	0.03722	2
Mombasa	Kenya	1012	1016	1376	0.000233 9	0	0.03717 2	2
Cebu	Philippines	708	1998	2074	0.000248 5	0	0.03649 3	3
Oran	Algeria	201	1225	1230	0.000244 1	0	0.03469 5	2
Kota Kinabalu	Malaysia	261	594	531	0.000226 6	453	0.03388 9	2
Rades	Tunisia	311	566	418	0.000232 5	0	0.03299 7	2
Montreal	Canada	1402	1763	1783	0.000245 5	0	0.03065 5	1
Agadir	Morocco	159	995	965	0.000232 9	0	0.03001 4	1
Kuching	Malaysia	228	119	104	0.000154	0	0.02811 5	2
Ambarli	Turkey	3445	176	40	0.000174 2	0	0.02803 1	2
Prince Rupert	Canada	618	3876	3365	0.000250 3	0	0.02762 2	3
Wilmington (Delaware, USA)	United States of America	339	247	283	0.000223	0	0.02738 7	0
Muara	Brunei	90	181	169	0.000181 5	0	0.02653 3	2
Jinzhou	China	879	454	410	0.000222 3	0	0.02577 8	3
Palm Beach	United States of America	263	61	53	8.72E-05	0	0.02547 2	0
Sfax	Tunisia	84	371	316	0.000238 7	0	0.02495 9	2
Rizhao	China	2420	1008	953	0.000237	0	0.02372 2	3
Cai Lan	Vietnam	49	80	96	0.000145 7	0	0.02196 7	3
Sandakan	Malaysia	275	174	164	0.000216 5	0	0.01774 7	2
Beihai	China	85	53	54	0.000117 6	0	0.01687 4	3

Pontianak	Indonesia	198	251	244	0.000229 2	0	0.01613 8	4
Bintulu	Malaysia	258	65	66	0.000113 5	0	0.01401 1	2
Haldia	India	102	44	40	0.000137 4	0	0.01370 4	2
Sihanoukville	Cambodia	342	20	9	8.51E-05	0	0.01345	2
Makassar	Indonesia	560	1934	1996	0.000242 6	9	0.01327 6	4
Balikpapan	Indonesia	76	203	188	0.000203 7	0	0.01264 1	4
Johore Bahru	Malaysia	793	69	78	0.000173 2	0	0.01223 6	2
Subic Bay	Philippines	77	34	59	0.000125 8	0	0.01044 6	3
Sousse	Tunisia	32	32	20	0.000148 3	0	0.01000 5	2
Nanjing	China	2760	9	7	4.07E-05	0	0.00994 3	3
Bitung	Indonesia	115	821	854	0.000238 6	0	0.00960 2	4
Dumai	Indonesia	N/A	9	20	3.93E-05	0	0.0075	4
New Mangalore	India	63	57	66	0.000191 9	0	0.00733 1	2
Banjarmasin	Indonesia	404	587	610	0.000235 2	0	0.00705 4	4
Jayapura	Indonesia	45	462	527	0.000227 1	0	0.00688 9	4
Sorong	Indonesia	44	420	433	0.000223 4	0	0.00640 5	4
Zhenjiang	China	385	20	20	0.000119 4	0	0.00610 6	3
Gulfport	United States of America	188	61	54	0.000197 6	0	0.00573 5	0
General Santos	Philippines	183	8	3	3.88E-05	0	0.00572 5	3
Yingkou	China	5768	3	3	2.02E-05	0	0.00531 7	3
Gabes	Tunisia	N/A	2	3	1.54E-05	0	0.00333 1	2
Zamboanga	Philippines	79	63	71	0.000165 8	0	0.00277 9	3
New Orleans	United States of America	491	1	3	1.19E-05	0	0.00156 6	0
Haiphong	Vietnam	2131	0	0	4.32E-06	0	0.00083 5	3

Source: Authors' calculations

Note: Ports for which we do not have data for the container throughput, in the first column is written "N/A".

2.C. Graphical representation of the “Maritime Port Network”



Source: Authors' visualization

Note: Maritime Network of 153 ports in the sample. The size of the nodes corresponds to their outdegree weighted centrality. The weight of the links is $w_{ij} = \text{AvgTEU}_{ij} * \text{NbTrips}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

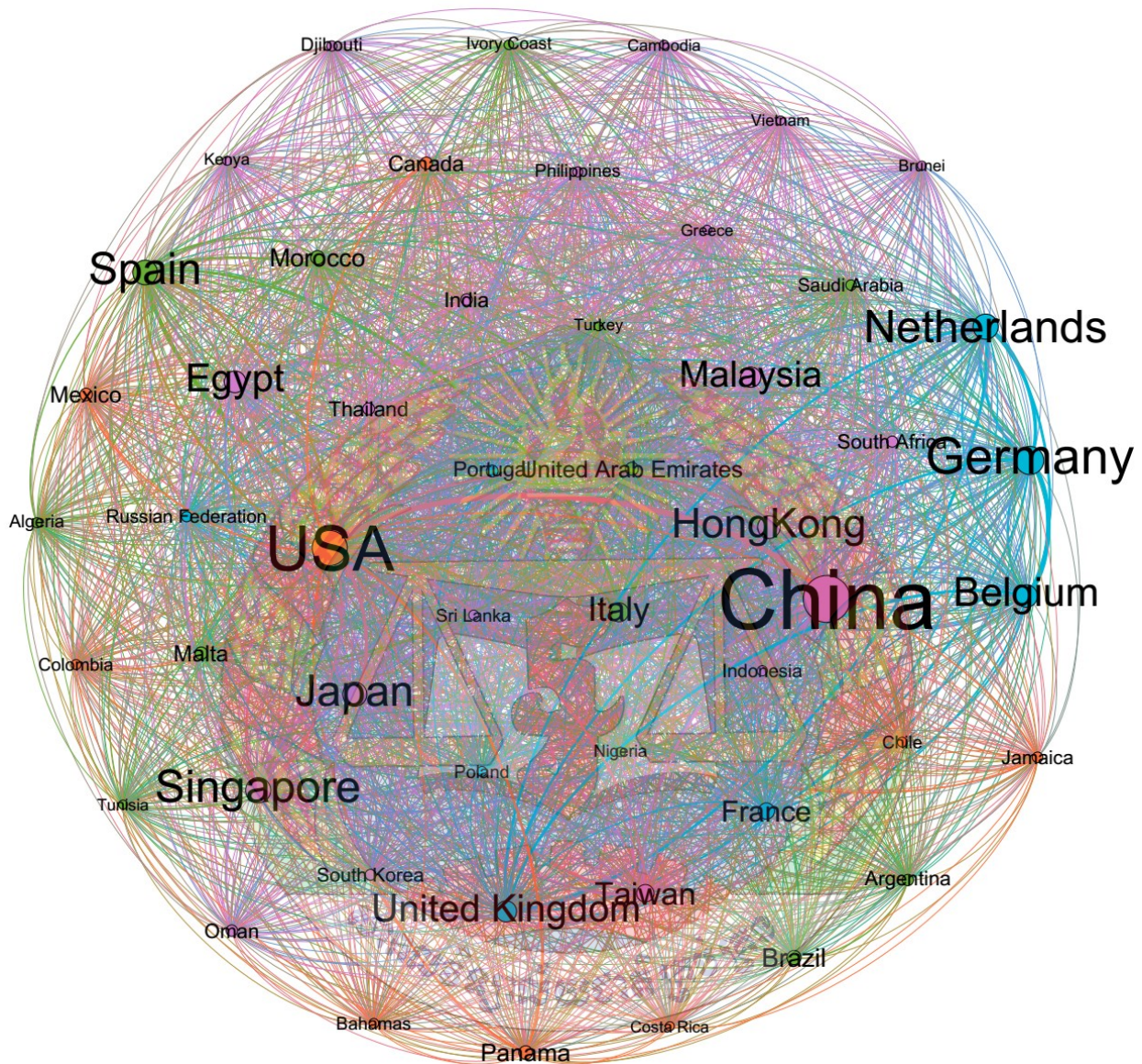
2.D. Main centralities measures for the “Maritime Country Network”

	Outdegree (weighted)	Indegree (weighted)	Closeness (weighted)	Betweenness (weighted)	Modularity class
China	274245.9349	214893.3266	0.001476585	1340	1
USA	189447.0602	198563.4553	0.001473832	907	3
Germany	138943.6659	132126.0366	0.001467422	283	0
Singapore	118439.5886	116885.4411	0.001466241	175	1
Netherlands	117762.6223	111116.5104	0.001465357	0	0
Spain	113742.9457	120195.603	0.001467584	517	2
Japan	110083.7562	110874.2683	0.001472465	302	1
Hong Kong	100215.6263	90127.35064	0.001466468	0	1
Belgium	97922.95869	115112.6899	0.001461832	112	0
Egypt	91756.90448	98788.85722	0.001472406	134	1
United Kingdom	86829.98145	86888.5614	0.001461372	0	0
Malaysia	81789.48812	65233.56405	0.001457743	185	1
Italy	72755.63338	72661.93602	0.001461525	49	2
Taiwan	62205.8106	59135.69895	0.001464884	98	1
France	53911.22997	56846.53733	0.001449089	0	0
Brazil	38064.80367	42023.31767	0.001447278	72	2
Morocco	35319.87228	35687.98169	0.001448902	0	2
Panama	34123.72181	40126.30958	0.001460087	98	3
United Arab Emirates	29833.27757	52413.19357	0.00143046	49	2
Malta	26547.3555	28325.43968	0.00143489	98	2
Mexico	25933.92338	29697.44283	0.001439135	0	3
Canada	23713.61258	23523.62632	0.001451423	0	3
Portugal	21729.69064	23018.96137	0.001430386	0	0
Thailand	20795.08862	19675.28744	0.001444595	0	1
India	18897.93228	18218.72608	0.001394731	0	1

Oman	18159.4615	16604.92881	0.001430872	0	1
Argentina	17427.35967	21111.75727	0.001418548	0	2
South Africa	16104.84046	16364.69071	0.00141785	0	1
South Korea	14628.41699	16895.96553	0.001437067	0	1
Jamaica	12513.44473	13633.36596	0.001448754	0	3
Saudi Arabia	11015.93787	14866.82175	0.001412726	0	2
Russian Federation	10201.34583	10213.12975	0.001437509	0	0
Indonesia	9580.712991	10552.96713	0.001408387	0	1
Djibouti	9429.537833	10869.15225	0.001399613	0	1
Poland	8417.0845	10629.5575	0.001399373	0	0
Philippines	7930.561252	8263.025147	0.001404214	0	1
Algeria	7814.442874	7664.00515	0.001431827	0	2
Sri Lanka	7308.548	8071.568875	0.00134095	0	1
Colombia	7049.846135	9961.630901	0.001400785	0	3
Bahamas	6568.56575	7485.537381	0.001411229	0	3
Chile	6279.103708	8356.0399	0.001378792	0	3
Ivory Coast	4752.393333	4562.753	0.001304529	0	2
Nigeria	2790.3435	4504.5505	0.001261346	0	2
Costa Rica	1376.884833	1627.843071	0.001238829	0	3
Kenya	1012.167	1369.598	0.000903352	0	1
Vietnam	1009.076071	951.3793333	0.001184533	0	1
Tunisia	974.8014047	744.4635615	0.001142024	0	2
Greece	227.7643333	289.8393333	0.000595443	0	1
Brunei	190.17	170.6823333	0.000697308	0	1
Turkey	180.596	41.1145	0.000377861	0	2
Cambodia	19.637	9.038	0.000102614	0	1

Source: Authors' calculations

2.E. Graphical Representation of the Maritime Country Network



Source: Authors' calculations

Note: Maritime Network of 51 countries in the sample. The size of the nodes corresponds to their outdegree weighted centrality. The weight of the links is $w_{ab} = \text{AvgTEU}_{ab} * \text{NbTrips}_{ab}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

2.F. Main centralities measures for the “ASEAN+3 Maritime Port Network”

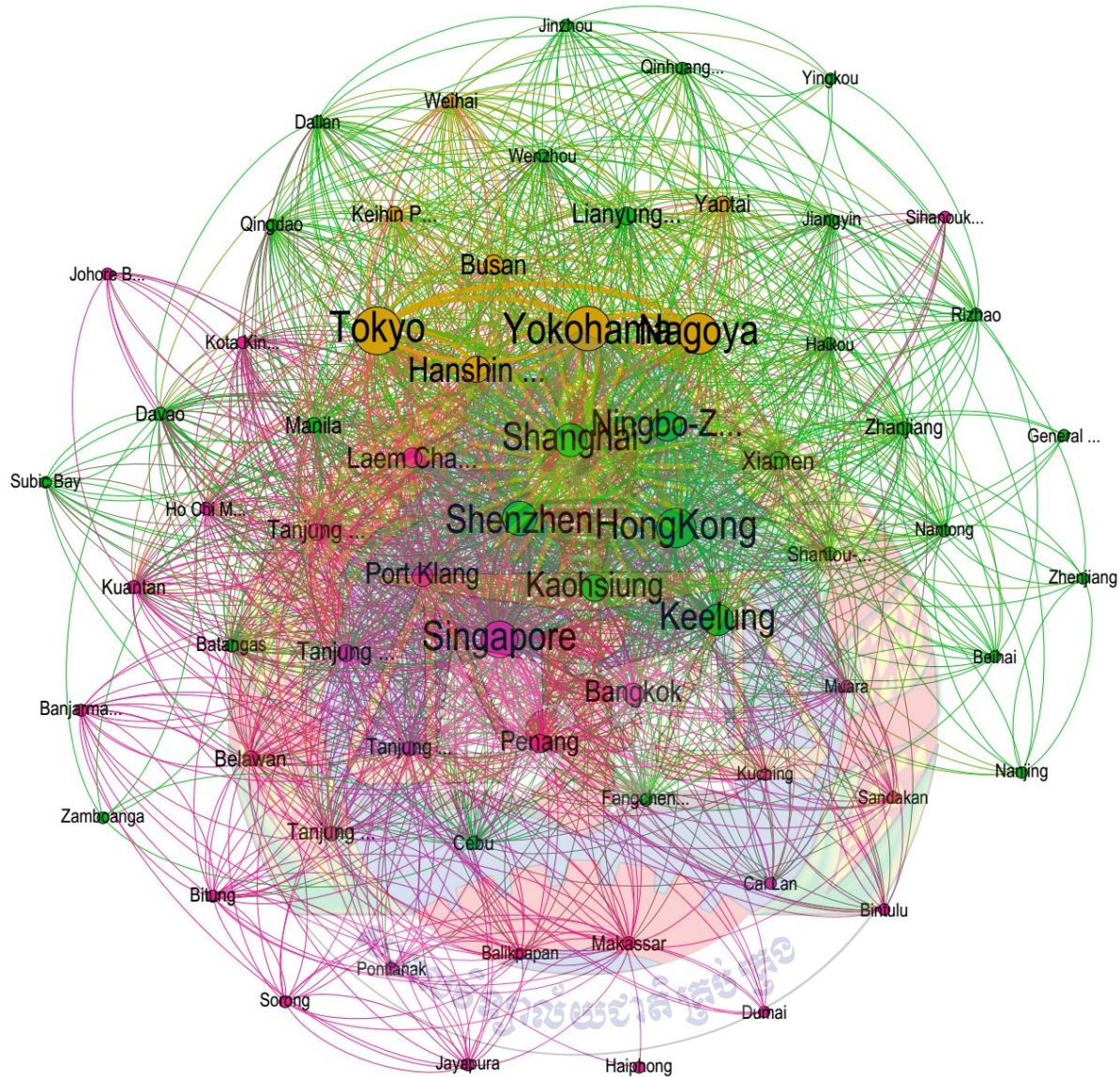
	Outdegree (weighted)	Indegree (weighted)	Closeness (weighed)	Betweenness (weighted)	Hub	Modularity class
Tokyo	49119.811	46318.16	0.00050424	753	0.172171	0
Yokohama	44580.529	44385.518	0.00050421	691	0.171899	0
Nagoya	39489.751	38961.453	0.00050389	62	0.174722	0
Hong Kong	37752.444	38192.85	0.00050417	1021	0.198175	2
Singapore	34270.252	31123.216	0.00050438	1922	0.197974	1
Shenzhen	30783.731	33489.861	0.00050407	868	0.188277	2
Shanghai	29211.148	31193.976	0.00050402	1383	0.191338	2
Keelung	26650.695	23864.959	0.00050358	124	0.16422	2
Ningbo-Zhoushan	24251.828	25510.307	0.00050389	220	0.180556	2
Kaohsiung	20460.397	21458.386	0.00050303	194	0.188148	2
Hanshin Ports	19962.309	21359.149	0.00050351	89	0.172841	0
Bangkok	13191.611	12584.185	0.00050204	268	0.159568	1
Port Klang	12400.297	11351.893	0.00050266	442	0.181426	1
Laem Chabang	10932.673	11200.227	0.0005019	141	0.174055	1
Busan	10819.218	11583.462	0.00050153	2	0.165258	0
Penang	9480.783	9389.609	0.00050293	0	0.169541	1
Lianyungang	8637.937	8021.87	0.00050023	14	0.153506	2
Xiamen	7579.1	7357.996	0.00050017	0	0.166509	2
Tanjung Priok (Jakarta)	7063.208	6907.406	0.00049804	562	0.173976	1
Tanjung Pelepas	6898.514	10347.44	0.00049803	131	0.169408	1
Yantai	5198.723	5180.446	0.00049666	0	0.143925	0
Manila	4390.887	4047.275	0.00049628	268	0.164934	2
Belawan	4267.08	4308.74	0.0005007	404	0.109855	1

Keihin Ports	4038.396	3671.607	0.0004983	0	0.15233	0
Tanjung Mas (Semarang)	3977.09	3989.372	0.00049972	177	0.112376	1
Tanjung Perak (Surabaya)	3549.345	4441.804	0.00049185	438	0.139004	1
Weihai	2867.379	2752.191	0.00048866	0	0.138798	0
Zhanjiang	2442.11	2451.399	0.00049522	132	0.116075	2
Shantou-Jieyang	2160.844	2184.55	0.00049476	0	0.144317	2
Cebu	1998.429	2039.835	0.00049666	0	0.101664	2
Makassar	1933.587	1995.592	0.00049021	9	0.042231	1
Davao	1825.59	1708.268	0.00048898	63	0.108711	2
Kuantan	1820.187	1809.408	0.0004965	0	0.103511	1
Fangchenggang	1735.105	1720.914	0.00049617	0	0.126141	2
Qingdao	1384.061	948.521	0.00049058	0	0.128494	2
Batangas	1137.65	1141.526	0.00048176	0	0.118669	2
Rizhao	1008.275	952.762	0.00048163	0	0.067906	2
Ho Chi Minh City	982.453	890.3	0.00048463	132	0.103761	1
Wenzhou	960.566	1000.182	0.00048299	0	0.135263	2
Qinhuangdao	825.349	848.993	0.00047893	0	0.090689	2
Bitung	820.913	854.208	0.00048473	0	0.032146	1
Kota Kinabalu	592.913	530.902	0.00046846	198	0.092254	1
Banjarmasin	587.105	609.736	0.00048036	0	0.024995	1
Jiangyin	510.166	259.495	0.00048078	0	0.105093	2
Dalian	504.319	277.357	0.00047084	0	0.10489	2
Haikou	473.86	467.08	0.00045791	0	0.117169	2
Jayapura	462.342	527.098	0.00046923	0	0.024342	1
Jinzhou	444.249	410.351	0.00046109	0	0.061534	2
Nantong	439.876	248.783	0.00047243	132	0.093807	2
Sorong	420.308	433.052	0.00046421	0	0.021769	1

Pontianak	241.217	234.329	0.00047187	0	0.039264	1
Balikpapan	202.74	188.267	0.00043624	0	0.042295	1
Muara	179.989	169.156	0.00040324	0	0.068501	1
Sandakan	174.314	164.176	0.00045274	0	0.050555	1
Kuching	119.111	102.494	0.00035821	0	0.080139	1
Cai Lan	79.846	96.27	0.00034197	0	0.059348	1
Johore Bahru	68.269	69.799	0.00038845	0	0.028937	1
Bintulu	65.343	66.116	0.00028237	0	0.038965	1
Zamboanga	63.108	71.218	0.00037702	0	0.01042	2
Beihai	53.294	54.396	0.00029055	0	0.047079	2
Subic Bay	32.136	57.469	0.00030667	0	0.026543	2
Zhenjiang	20.349	20.2	0.00029374	0	0.016134	2
Sihanoukville	19.637	9.038	0.00022367	0	0.034609	1
Nanjing	8.55	6.318	0.00011661	0	0.026157	2
General Santos	8.07	2.69	0.00011253	0	0.013949	2
Dumai	3.906	20.024	9.4755E-05	0	0.010836	1
Yingkou	2.908	2.55	6.0473E-05	0	0.014053	2
Haiphong	0.26	0.26	1.3405E-05	0	0.003656	1

Source: Authors' calculations

2.G. Graphical representation of the ASEAN+3 Maritime Port Network



Source: Authors' visualization

Note: Maritime Network of the 68 ports in the sample which are associated with ASEAN+3 community. The size of the nodes corresponds to their outdegree weighted centrality. The weight of the links is $w_{ij} = \text{AvgTEU}_{ij} * \text{NbTrips}_{ij}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

2.H. Main centralities measures for the “ASEAN+3 Maritime Country Network”

Node	Outdegree (Weighted)	Indegree (weighed)	Closeness (weighted)	Betweenness (weighed)	Hub	Modularity Class
Brunei	188.682	170.6823	0.000873	0	0.198899	1
Cambodia	19.637	9.038	0.000254	0	0.199081	1
China	72001.16	70907.82	0.001167	20	0.293203	0
Hong Kong	39415.85	41034.54	0.001165	0	0.302092	0
Indonesia	9457.76	10398.21	0.001153	0	0.272449	1
Japan	78216.16	78690.86	0.001168	83	0.294955	0
Malaysia	19874.3	20767.24	0.001163	33	0.302092	1
Philippines	7604.649	7739.231	0.00115	0	0.268245	0
Singapore	35240.5	30512.55	0.001167	24	0.302092	1
South Korea	10449.38	12686.64	0.001159	0	0.274202	0
Taiwan	36636.58	36165.08	0.001165	22	0.302092	0
Thailand	17248.96	17334.35	0.001161	0	0.291449	1
Vietnam	1009.076	946.4733	0.001088	0	0.276565	1

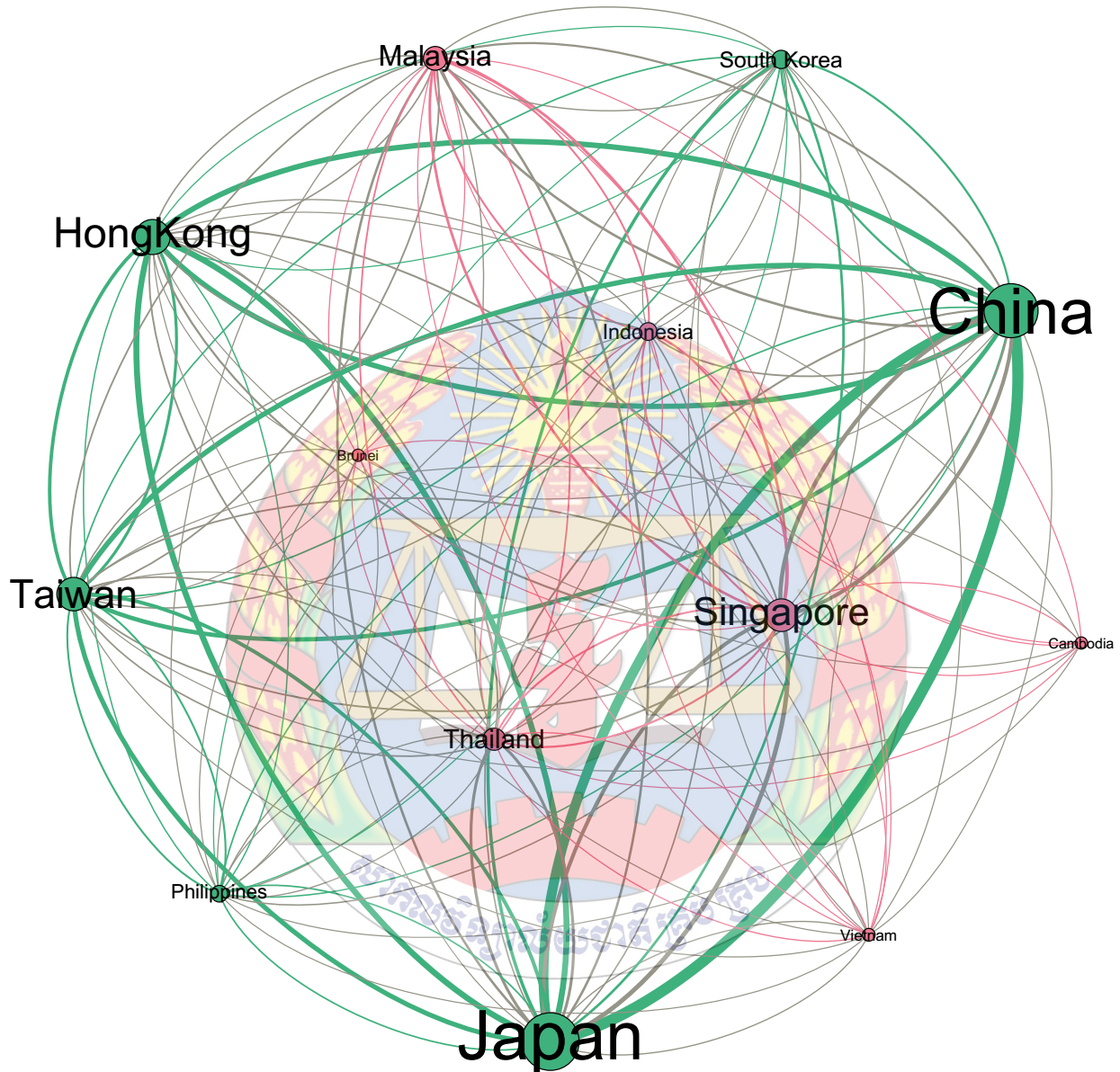
Source: Authors' calculations

2.I. Main centralities measures for the “ASEAN+3 Export Country Network”

Node	Outdegree (weighted)	Indegree (weighted)	Closeness (Weighted)	Betweenness (Weighted)	Modularity Class
Brunei	5252.399	7946.597	0.005739	0	0
Cambodia	14838.35	1704.748	0.015294	0	0
China	800010.4	919958.9	0.017397	101	1
Hong Kong	553798.3	371891.2	0.01723	0	1
Indonesia	133570.8	99665.92	0.016174	0	0
Japan	338632	359284.8	0.017368	42	0
Malaysia	157607.7	145422.8	0.016319	0	0
Philippines	78707.57	41717.35	0.015253	0	0
Singapore	190761.7	271385.6	0.016392	12	0
South Korea	224272.7	303784.8	0.016781	0	0
Taiwan	151726.5	216453.9	0.016211	0	0
Thailand	126921.3	119201.9	0.015923	11	0
Vietnam	144938.6	62619.71	0.016736	0	0

Source: Authors' calculations

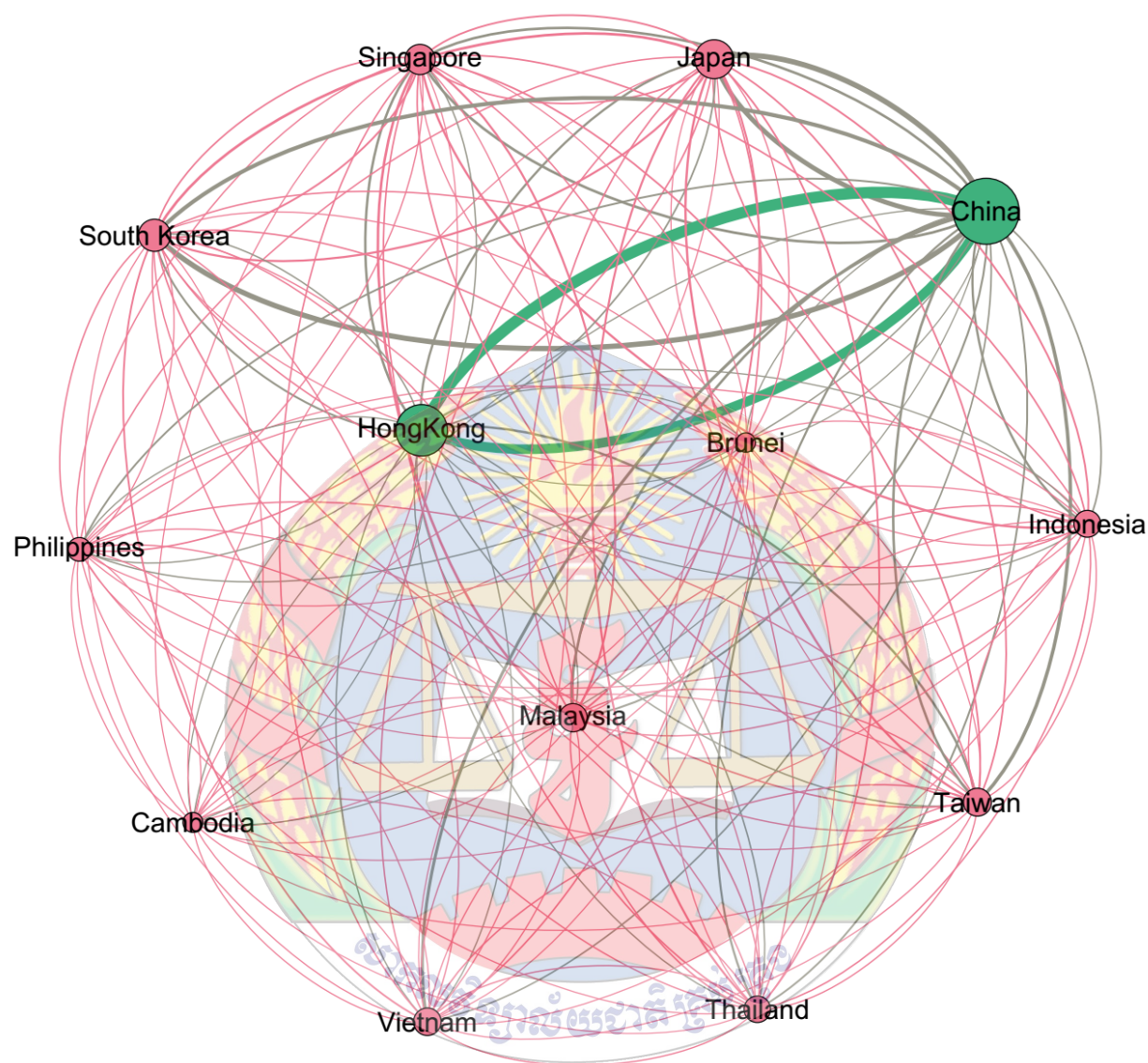
2.J. Graphical representation of the ASEAN+3 Maritime Country Network



Source: Authors' calculations

Note: Maritime Network of the 13 countries belonging to ASEAN+3 community. The size of the nodes corresponds to their outdegree weighted centralities. The weight of the links is $w_{ab} = \text{AvgTEU}_{ab} * \text{NbTrips}_{ab}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

2.K. Graphical representation of the ASEAN+3 Export Country Network



Source: Authors' calculations

Note: Export Trade Network of the 13 countries belonging to ASEAN+3 community. The size of the nodes corresponds to their outdegree weighted centralities. The weight of the links is $w_{ab} = \text{EXP}_{ab}$. The different colours of edges and nodes correspond to the modularity classes (closely linked nodes).

Chapter 3. Relative efficiencies of ASEAN container ports based on Data Envelopment Analysis



Relative efficiencies of ASEAN container ports based on Data Envelopment Analysis

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Abstract

Ports play a critical role in the economies of many countries in the ASEAN region. Efficient ports facilitate a country's imports and exports, and the "relative efficiency" of a port can be evaluated based on its efficiency compared to other similar ports. This study analyzes the relative efficiencies of 49 ASEAN container ports and terminals. These ports are categorized according to their container handling system and location (those located in a riverbank connected to the sea are called "inland ports" and those by the seaside are called "seaports"). The traditional output-oriented data envelopment analysis method is applied in this study. Results show that seaports operate on a better efficiency scale than inland ports. Most of the ASEAN ports operate under increasing returns to scale, which suggests that they have not reached their optimum size. These findings could be useful for port managers to assess by how much the container traffic could be increased in ASEAN and which the most efficient container terminals are. Moreover, policy makers may consider the results in order to improve the trans-ASEAN transport network and ASEAN trade competitiveness.

Keywords: Data Envelopment Analysis, Container Ports; Efficiency, ASEAN

3.1. Introduction

The hub-and-spoke structure of the Container Liner Shipping industry implies that a large part of the containership traffic is concentrated in a small number of large ports. In addition, the size of the containership has not ceased to increase, which adds pressure to berth and crane operations (UNCTAD, 2017). In order to avoid congestions and to remain competitive, ports should constantly optimize their operations. As connecting links between different transport modes in the global logistics chain, container terminals are vital to the efficiency of the whole chain. Indeed, the level of port efficiency greatly affects a country's productivity and competitiveness (Wu and Goh, 2010).

However, in the last decade the inter-port competition has intensified (Fan et al., 2009). Port markets used to be perceived as monopolistic due to the exclusive and immovable geographic locations of the ports and the unavoidable concentration of port traffic. However, the rapid development of international container and intermodal transportation has drastically changed the market structure from that of a monopoly to that of fierce competition in many parts of the world (Cullinane and Wang, 2006). Along with these trends, the economy is becoming more regional (Rex et al., 2015, UNCTAD, 2015). A recent example was the establishment of the ASEAN Economic Community (AEC) in 2015. The AEC offers opportunities in the form of a market of US\$2.6 trillion and over 622 million people. As of 2014, the AEC was collectively the third largest economy in Asia and the seventh largest in the world and accounted for 14% of the world container throughput. As ASEAN has designated 47 main ports in the trans-ASEAN transport network, these ports face a number of challenges in providing more efficient shipping network services given the varying levels of port infrastructure development (ASEAN, 2010). Thus, it is necessary to analyze the efficiency and productivity of these ports in order to pursue the realization of the ASEAN Single Shipping Market (ASSM).

This study evaluates the relative efficiency of 49 ASEAN container ports and terminals. The objective of the research is to highlight the most efficient ports in the sample according to their type (inland port or seaport) and their container yard equipment. Such categorization is necessary because in order to apply the data envelopment analysis method, we need to compare homogenous

units (Kutin et al.). The traditional DEA output-oriented models are applied to determine the target values of the outputs for each port.

The important contributions of this study include providing a benchmarking analysis based on the DEA method and assisting decision makers in their ports' development operations and the improvement of the trans-ASEAN transport network.

3.2. Literature Review

Production optimization has been analyzed by many researchers. (Debreu, 1951) established the first measure of productive efficiency with his concept of the coefficient of resource utilization. Farrell (1957) proposed a similar method of measuring efficiency by including multiple inputs and outputs. The so-called input-based Farrell efficiency can be defined as the maximum proportional contraction of all inputs that allows the production of the same amount of output. In the opposite case, the output-oriented Farrell efficiency measures the proportional expansion of all outputs with a given amount of inputs.

There are two types of efficiency: allocative (Grammenos) and technical. The former represents the optimal combination of inputs and outputs under the assumption that the producer wants to minimize costs, whereas the latter is associated with the effectiveness with which a given set of inputs is used to produce an output. The main drawback of the Farrell efficiency is the attribution of weights to the inputs and outputs. To overcome this problem, Charnes et al. (1978) defined an optimization method based on mathematical programming. They developed the DEA method with constant returns to scale (CRS), or the so-called DEA-CCR. This method allows the measurement of the relative efficiency of decision-making units (DMUs) without attributing any predetermined weights or conducting at any time series analyses. This method was extended by Banker, Charnes, and Cooper (BCC) (1984) to include variable returns to scale (VRS) and is also known as DEA-BCC. Since then, the DEA has been extended in multiple ways, incorporating, for example, dummy or categorical variables, discretionary and non-discretionary variables, nonparametric Malmquist indices, etc. This study applies the traditional DEA-CCR and DEA-BCC methods and the objective is to determine the most efficient ports in the ASEAN region. As

DEA is suited for the comparison of homogenous units such as container ports, a common feature of port benchmarking studies is the use of operational data due to the difficulty of obtaining a port's costs and prices (Bichou, 2013). Thus, this study focuses on technical efficiency measurements.

Table 3.1 provides an overview of DEA use in the literature to evaluate the relative efficiencies of container terminals and ports. In this list, the sample size generally varies between 10 and 70 DMUs, and Bichou (2013) is the only study that analyzes a considerable number of terminals, i.e., 420. The most commonly applied DEA methods are the traditional ones, DEA-CCR and DEA-BCC. In the literature, the selected inputs are usually the terminal area, the quay length, the number of container berths, the number of quay cranes, and the number of employees. In order to compare homogenous units using similar technologies, some authors include other specific indicators regarding the port's infrastructure, such as the number of tugs, the number of straddle carriers, the number of reach stackers, etc. The most suitable indicator to evaluate the ports' production is the annual container throughput in TEUs, as the main purpose of any container terminal is to handle as many containers as possible. Another potential output indicator is the number of ship calls. Two studies use non-conventional indicators as inputs or outputs. Hai-bo and He-zhong (2009) evaluate the allocative efficiencies of 13 port companies in China by taking into account net permanent assets and total employees as production factors and the main business revenues as output. The study conducted by de Almeida Guimarães et al. (2014) evaluates the environmental performances of 15 Brazilian container terminals using total energy consumption, the consumption of non-renewable energy, sewage emissions, office supply consumption, CO₂ emissions, and water consumption as inputs and container throughput as an output.

By using DEA-BCC, DEA-CCR, and panel data, the empirical results of Bichou (2013) show that most of the container terminals clearly utilize a VRS production technology. Similarly, Hung et al. (2010) conclude that the overall technical inefficiencies of Asian container ports are primarily due to pure technical inefficiencies rather than scale inefficiencies. Only 26% of Asian container ports are regarded as efficient. This result also suggests that port managers should focus first on improving their management practices to meet the market requirements of container ports, and then container ports can be subject to improvements in their scale efficiencies. Cullinane and Wang (2006) conduct a rather arbitrary dichotomous classification of the sample between large

and small ports on the basis of a cut-off throughput of 1 million TEUs per annum. Their findings suggest an association between large ports and decreasing returns to scale and between small ports and increasing returns to scale. In Tongzon (2001), the underutilization of labor is highlighted as a primary source of inefficiency for 11 out of 12 ports in the sample. Wanke (2013) shows, based on a two-stage network DEA model to calculate the physical infrastructure and shipment consolidation efficiency levels, that just 7 out of 27 (25.9%) ports achieved 100% efficiency. The results of DEA-CCR for 19 container terminals in the Middle East show that 84.21% of the terminals are inefficient (Almawshaki and Shah, 2015). Dan et al. (2013) assess the efficiency of coastal container terminals in China via a three-stage DEA model. The overall coastal container terminal efficiency is relatively low because of scale inefficiency, and there is a vast regional difference in terminal efficiency across different port groups. In addition, there is a serious input excess in coastal container terminals in China of approximately 35%.

The main conclusions of the literature review are as follows: a) there is a need to find appropriate criteria to categorize container terminals; b) the sample sizes in these studies range from 11 to 420 container terminals; c) the output most commonly used by researchers is the annual container throughput; d) for a small sample with homogenous ports, it is appropriate to apply only DEA-CCR; and e) for a larger sample with ports of different sizes, both DEA-CCR and DEA-BCC should be applied.

Table 3.1: Non-parametric method in analyzing the relative efficiency of container ports and terminals

Authors	Model	Sample and region	Inputs	Outputs
(Almawshaki and Shah, 2015)	DEA-CCR	19 container terminals in the Middle East	Terminal Area; Quay length; Quay cranes; Yard equipment; Maximum Draft	Container throughput
(Bichou, 2013)	DEA-CCR; DEA-BCC; Panel data	420 container terminals	Terminal area; Max draft; Quay length Quay crane Index; Yard-stacking index Gates	Container throughput
(Bray et al., 2014)	Fuzzy DEA	16 container ports	Number of cranes; Container berths; Number of tugs; Terminal area; Delay time; Number of port authority employees	Container throughput; Shiprate; Shipcalls; Crane; productivity

(Cullinane and Wang, 2006)	DEA-CCR; DEA-BCC;	57 container ports	Terminal Area; Quay cranes; Yard cranes Straddle Carriers	Container throughput
(Cullinane et al., 2006)	DEA-CCR; DEA-BCC	30 container ports	Terminal length; Terminal area; Quay cranes Yard gantry cranes; Straddle carriers	Container throughput
(Morales Sarriera et al., 2013)	DEA-CCR DEA-BCC	63 container ports in Latin America and the Caribbean	Quay length; Terminal area; Mobile cranes with more than 14 t. capacity; STS gantry cranes	Container throughput
(González and Trujillo, 2008)	Parametric and DEA	10 Spanish ports	Length of berths; Port area; Number of employees	Containers Liquid bulk Other cargo Passengers
(de Almeida Guimarães et al., 2014)	DEA-CCR; DEA-BCC.	15 Brazilian container terminals	Total Energy; Non-renewable energy Sewage emission; Office supplies consumption; Total emissions and Water consumption per worker	Container Throughput
(Hai-bo and He-zhong, 2009)	SFA	13 port companies in China	Net permanent asset; Total employees	Main business revenue
(Hung et al., 2010)	DEA-CCR; DEA-BCC; DEA with bootstrap method	31 container ports in Asia-Pacific	Terminal area; STS container gantry cranes (No); Berths (No); Total quay length	Container throughput
(Jiang and Li, 2009)	DEA-CCR; DEA-BCC.	12 container ports in Asia	Import/Export by customs; GDP by regions Berth Length; Crane number	Container throughput
(Dan et al., 2013)	DEA; SFA	42 Coastal ports on China	Terminal length Handling equipment (bridge, mobile and beam cranes) Number of employees	Container throughput
(Lim et al., 2011)	Additive non-oriented DEA RAM	26 Asian container terminals	Quay length; Total area; Gantry Cranes	Container Throughput
(Lozano et al., 2011)	Centralised DEA using a non-radial Russell measure of technical efficiency.	50 Spanish container ports	Land and stacking area; Total quay length Total number of cranes; Number of tugs	Total port traffic Container Throughput Ship calls
(Núñez-Sánchez and Coto-Millán, 2012)	Malmquist index	46 ports in Spain	Number of employees; Intermediate consumption; Capital	Liquid bulk Solid bulk Containerized general cargo Non-containerized general cargo
(Sharma and Yu, 2010)	Tree based DEA	70 container terminals	Quay cranes; Transfer cranes; Straddle carriers; Reach stackers; Quay length Terminal area	Container throughput

(Tongzon, 2001)	DEA-CCR; Additive DEA.	4 Australian and 12 other international container ports	Number of cranes; Number of container berths Number of tugs; Terminal Area; Delay time Labor (units)	Container throughput Number of shipcalls
(Wanke, 2013)	Network-DEA centralized efficiency	27 Brazilian ports	Number of berths; Warehousing area Yard area; Container frequency (shipments)	Container throughput
(Wilmsmeier et al., 2013)	Malmquist index	40 ports in Central and South America	Terminal area; Ship-to-shore crane capacity equivalent; Number of employees	Container throughput
(Wu and Goh, 2010)	DEA-CCR; DEA-BCC; DEA Windows Analysis.	21 major international container ports	Terminal area; Total quay length No. of pieces of equipment	Container throughput

Source: Collected by Authors.

Note: DEA-CCR refers to Data Envelopment Analysis based on Charnes, Cooper & Rhodes (DEA model addressing the Constant Returns to Scale). DEA-BCC refers to DEA based on Banker, Charnes and Cooper (DEA model addressing the Variable Returns to Scale). RAM refers to Range Adjusted Measure. SFA refers to Stochastic Frontier Analysis.

3.3. Methodology: Conceptual Framework and Measures

DEA provides a mathematical programming method of estimating the best practice production frontier and evaluating the efficiencies of different DMUs. In this study, DMUs are container terminals or container ports. This approach finds the smallest set enveloping the input-output observations for all DMUs, hence the name “data envelopment analysis”. DEA models can be input and output oriented. The former minimizes the inputs for a given set of outputs, whereas the latter maximizes the outputs for a given set of inputs. In this study, the output-oriented DEA-BCC and DEA-CCR models have been applied. Only output-oriented models are selected because port managers are more interested in how they can increase the container throughput rather than how to decrease their inputs. In addition, inputs such as depth at berth, number of berths, and container yard size are very costly to reduce. Seven inputs are used for some of the models. In these cases, it is hard to provide any recommendations about the reduction of inputs due to the fact that DEA has no predetermined weights on inputs and outputs. Since there is only one output (container throughput) in applied DEA output-oriented models, precise results regarding the relative efficiencies of ports and their capacities to increase their productivity can be provided.

When K is the number of DMUs, firm “ k ” uses a combination of m inputs denoted as $x_k = (x_{1k}, \dots, x_{mk}) \in \mathbb{R}_+^m$ to produce n outputs $y_k = (y_{1k}, \dots, y_{nk}) \in \mathbb{R}_+^n$. Let $\lambda_k = (\lambda_1, \dots, \lambda_K) \in \mathbb{R}_+^K$ being non-negative vector which forms the linear combination of the K firms. Finally, we have the technology set or production possibilities set: $T = \{(x, y) \in \mathbb{R}_+^m \times \mathbb{R}_+^n \mid x \text{ can produce } y\}$.

The reference technology (benchmark) set is T^* , which is constructed according to the minimum extrapolation principle. It is the smallest set of $\mathbb{R}_+^m \times \mathbb{R}_+^n$ that contains the data $x^k, y^k, k = 1, \dots, K$, and satisfy certain technological assumptions.

Following Bogetoft and Otto (2011), the output-oriented DEA model can be presented mathematically as follows:

$$F^0 = F((x^0, y^0); T^* = \{F \in \mathbb{R}_+ \mid (x^0, Fy^0) \in T^*\})$$

F^0 is the output efficiency score of DMU “0”. F^0 is obtained by the resolution of the following maximization problem.

$$\begin{aligned} & \max_{F, \lambda^1, \dots, \lambda^K} F \\ \text{s.t.} \quad & x^0 \geq \sum_{k=1}^K \lambda^k x^k \quad (1) \\ & F\lambda^0 \leq \sum_{k=1}^K \lambda^k y^k \quad (2) \end{aligned}$$

Constraint (1) implies that the inputs of DMU “0” must be greater than or equal to the sum of the weights (λ) multiplied by the inputs of the other DMUs in the sample, and constraint (2) indicates that the output efficiency score of DMU “0” multiplied by its real output must be less than or equal to the sum of the weights attributed to all other DMUs multiplied by their outputs.

In the DEA model, the efficiency score is computed under the assumption of different economies of scale. Each assumption involves adding one of the following constraints:

- $\forall \lambda_k \geq 0$, if the efficiency score represents the operation of the DMU under constant returns to scale (CRS).

• $\forall \lambda_k \geq 0$ and $\sum_{k=1}^K \lambda_k = 1$, if the efficiency score is computed under the assumption of variable returns to scale (VRS).

• $\forall \lambda_k \geq 0$ and $\sum_{k=1}^K \lambda_k \leq 1$, if the efficiency score is calculated under the assumption of decreasing returns to scale (DRS).

• $\forall \lambda_k \geq 0$ and $\sum_{k=1}^K \lambda_k \geq 1$, if the efficiency score depicts how the DMU operate under increasing returns to scale (Hirschman)

When $F^0 = 1$, the DMU “0” is efficient and it is a benchmark for at least one inefficient DMU. The F^0 scores of inefficient DMUs are smaller than one. For each of these DMUs, we can find the target output value (the output that the DMU can produce with its current set of inputs if it achieves efficiency) by dividing the original output by the efficiency score, $Target\ Value^0 = n^0 / F^0$.

Thus, DEA identifies the most efficient DMUs and shows by how much the inefficient DMUs could increase their outputs. By estimating the scores of a given unit under CRS and VRS, the scale efficiency (SE) can be computed.

$$SE^0 = \frac{F_{crs}^0}{F_{vrs}^0}$$

A DMU with an SE score closer or equal to one has an optimum scale of production. The source of its inefficiency is related to the management of the organization. If a DMU has an SE score considerably smaller than one, it means that the observed DMU operates on an inefficient scale, and, according to the efficiency scores under DRS and IRS, it should either increase or decrease its size.

DEA models can identify the most efficient DMUs. However, if all of them have the same score of one, it is impossible to rank them. Therefore, the concept of super-efficiency has been introduced. Super-efficiency measures are constructed by excluding the evaluated firm and checking how the efficiency frontier would change. Thus, the reference technology set could be written as $T^*(\gamma | -k)$, where γ refers to the different assumptions of DEA. We compute the optimal solution by excluding DMU “k”.

$$F^{sup} = F\left((x^k, y^k); T^*(y|-k)\right)$$

The super-efficiency measures on the input and output sides are not restricted to either greater than or less than one. On the output side, $F^{sup} k$ (the super-efficiency score of firm k) is less than one when the DMU has reduced all of its outputs by a factor of $F^{sup} k$ without being dominated by another firm (Bogetoft and Otto, 2011). However, in some cases, the Farell-based super-efficiency may not provide feasible solutions $F^{sup} k = -\infty$. The presence of infinite super-efficiencies simply means that there are no other units against which to gauge firm k with the given data and the imposed technological regularities. Such DMUs can be defined as hyper-efficient (Bogetoft and Otto, 2011). Such infeasible solutions appear frequently in the cases of DEA-VRS models.

In this study, the efficiency CRS and VRS scores have been computed by using “Win4Deap2⁶³” software. The CRS super-efficiency measures were calculated with “R⁶⁴” software and its “Benchmarking⁶⁵” package.

3.4. Data

DEA can be used only to compare homogenous units using similar technologies. In order to choose the most appropriate indicators, one must examine how a container terminal operates.

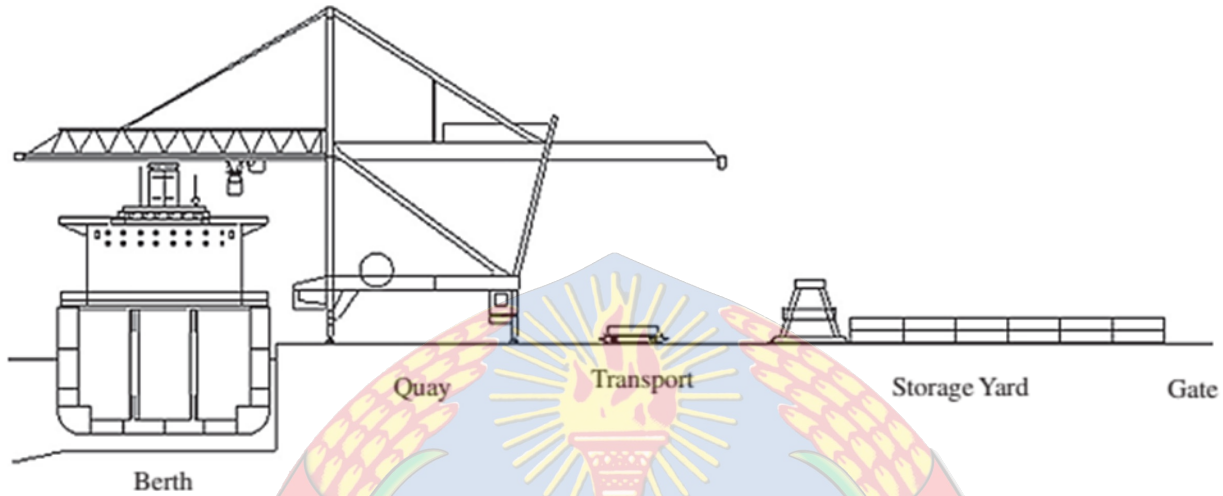
The container seaports can be categorized into two main types: “inland ports” and “seaports.” The former normally has a smaller capacity, located on a riverbank connected to the sea, and handles small container vessels (less than 2,000 TEUs), whereas the latter has a larger capacity, located on the seashore, and serves much larger container ships, up to Triple E class ships of 16,000 TEUs.

⁶³ <http://www.sigmdel.ca/aed-dea/install2-en.html>

⁶⁴ <https://www.r-project.org/>

⁶⁵ <https://cran.r-project.org/web/packages/Benchmarking/Benchmarking.pdf>

Figure 3.1. Container terminal area



Source: (Carlo et al., 2014)

Another way to categorize the container ports is according to their handling systems (Figure 3.1), which include “quay side crane” handling systems and “yard” handling systems. The former is the so-called “ship-to-shore crane” or “quay crane,” which handles containers from the ship to temporary buffer areas and vice versa. This type includes the Panamax gantry crane, the Post-Panamax gantry crane, and the Super Post-Panamax gantry crane, which serve Panamax container ships, Post-Panamax container ships and Super Post-Panamax container ships, respectively. The second type of handling systems works in container yards only and includes yard gantry systems, such as rail-mounted gantry systems (RMGs) and rubber-tired gantry systems (RTGs); straddle carrier system (SCs); and forklift truck systems (FTs), including reach stackers and front loaders. Yard gantry systems are used for large terminals, whereas the latter systems are used for smaller terminals. Most popular is the mixed system, in which two or even three types of handling systems are used at the same time. In addition, containers are transferred from temporary buffer areas to yards by container-trucks, transtainers, or straddle carriers, depending on the terminal operation. In this study, note that SC systems are also counted as yard gantry systems for further analysis.

In the sample, all container terminals use a mixed system of handling containers in the storage yard, combining forklifts with RTGs and/or RMGs. Only one terminal, North (Port Klang) has a SC system. Most of the ASEAN terminals use forklifts with RTGs. In the sample, four inland ports and 22 seaports have such equipment. Only four terminals (all of them inland) have RMGs and FTs. Another four ports use RMGs, RTGs, and FTs. The dataset used in this study can be found in Appendix 3.A.

Due to the small number of container terminals handled by only SC and RMG systems, it is impossible to create additional categories according to the type of yard equipment, but it should be emphasized that more than one category of handling system are used for container terminals nowadays. Therefore, this study categorizes the port and its terminal, with its current yard handling system, into six groups:

Category 1: Inland ports and seaports with yard gantry systems and SCs;

Category 2: Inland ports and seaports with RTGs and FTs;

Category 3: Seaports/terminals with yard gantry systems and FTs;

Category 4: Seaports/terminals with RTGs and FTs;

Category 5: Inland ports, regardless of their yard handling equipment;

Category 6: Inland ports with yard gantry systems (including SCs).

Table 3.2: Container yard handling systems

Number of ports	Type	Container yard handling systems					
		RTG + Forklift	MRGC + Forklift	MRTG + RTG + Forklift	Forklift	Straddle Carriers + RTG + Forklift	RTG
17	Inland	7	4	1	5	0	0
32	Seaport	22	0	3	5	1	1
49	Total	30	4	4	10	1	1

Source: Authors' collection

Table 3.3: Inputs used for the DEA analysis for each category of port and its terminals

	Sample Size	Max depth at berth (m)	Size of the container Yard (m ²)	Length of the quays (m)	No of Quay Cranes	No. of RTG C	No of Yard cranes (MRGC+ SC + RTGC)	No of Forklifts	No. of Trucks
Category 1	37	X	X	X	X		X	X	X
Category 2	29	X	X	X	X	X		X	X
Category 3	25	X	X	X	X		X	X	X
Category 4	22	X	X	X	X	X		X	
Category 5	16	X	X	X	X				
Category 6	12			X			X		

Source: Authors' collection

The first category includes the largest number of ports, including all inland ports and seaports with yard cranes (any type) and quay cranes. This category takes into account seven input indicators. All types of yard cranes (RTG, RMG, and SC) are summed up into one input indicator (number of yard cranes in the container yard). In the second category, inland and sea container ports and terminals with RTG and FT systems are compared. In the third category, only seaports with yard cranes are included, and in the fourth category, seaports with RTG and FT handling systems are included. Inland ports and terminals, regardless of their handling equipment in the container yard, are grouped in the fifth category. Finally, the last category compares inland ports with yard gantry systems, which includes SCs.

The maximum number of inputs that can be used with respect to the number of DMUs is given by the rule of thumb:

$$\# DMUs > 3(m + n)$$

Hence, for categories four, five, and six, some inputs must be eliminated from the analysis due to the small number of DMUs in the sample. Inputs were excluded based on their level of correlation with the other inputs.

We collected the data from various sources, such as port websites, reports, articles and other sources. Unfortunately, there is no database that contains the equipment and infrastructure of the ASEAN container ports. Considering the fact that the industry is facing huge issues in terms of oversupply and congestions, such a database could be very useful for decision makers.

3.5. Results

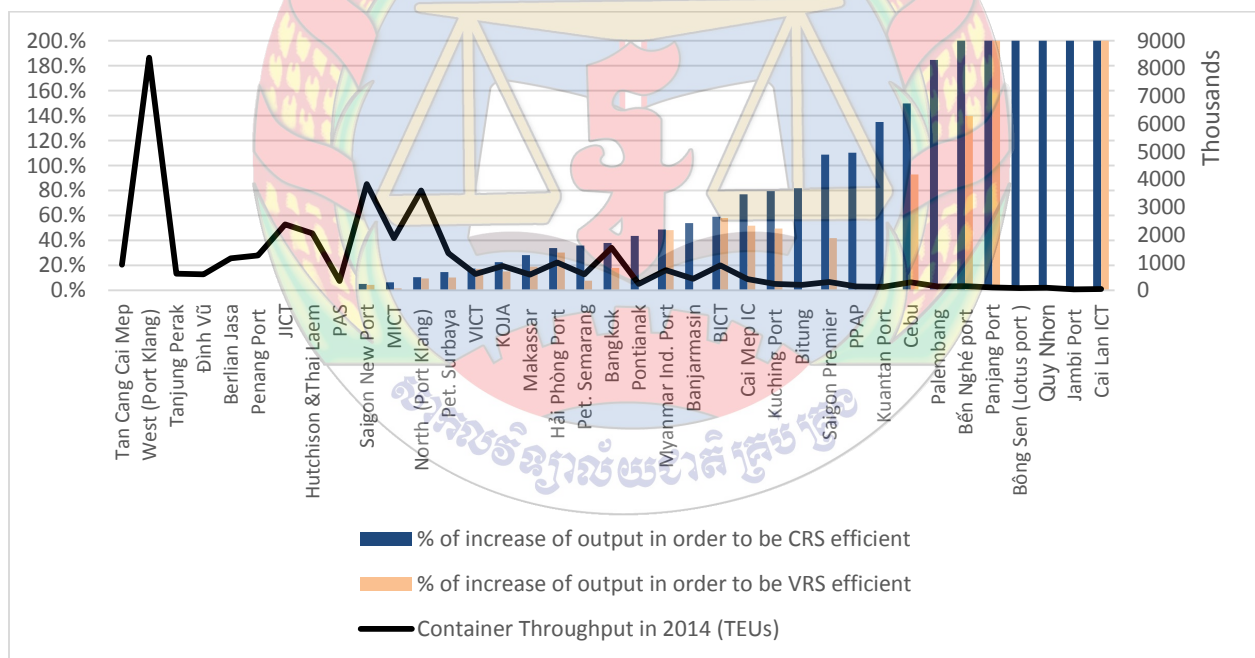
Fifty container terminals and ports were categorized into six groups. Some terminals appear in more than one group. For all of the groups, we have used as an output the annual container throughput measured in number of TEUs in 2014. In this section, we describe the main results of the output DEA-CCR and DEA-BCC models applied in the survey.

3.5.1. Inland ports and seaports with yard gantry systems and SCs

The first group includes all inland and sea container ports and terminals with yard cranes or SCs in the storage area. Ports that have only forklift systems in the container yard were not included in this category. Figure 3.2 shows by how much the ports in the first category should increase their output (container throughputs) to become efficient. In order for the results to be visible on the graph, we limit the displayed upper boundary percentage to 200% for all ports that have to increase their output by more than 200% to become efficient. The ports are ranked from left to right according to their super-efficiency measures. As we can see, the most efficient port is Tan Cang-Cai Mep (a terminal belonging to Saigon New Port, Vietnam), followed by West (Port Klang) (Malaysia) and Tanjung Perak (Indonesia). There is only one inland port that appears to be efficient, Đình Vu (Vietnam). The most inefficient ports are Ben Nghe (Vietnam), Panjang Port

(Indonesia), Bông Sen - Lotus Port (Vietnam), Quy Nhon (Vietnam), Jambi Port (Indonesia), and Cai Lan ICT (Vietnam). These inefficient ports must increase their container throughput by more than 200% in order to be on the efficiency frontier. It is also observed that these ports have an annual container throughput of around 100,000 TEUs. The results about this category are depicted in Appendix 3.B. On average, the ports in the sample score well in terms of scale efficiency (0.802). The source of inefficiency is related to their small size, because most of them are operated under increasing returns to scale. There are only four ports that are experiencing decreasing returns to scale (DRS), namely, Belawan ICT (Malaysia), North (Port Klang) (Malaysia), Saigon New Port (Vietnam), and Hai Phong Port (Vietnam). The size of these ports has a negative effect on their performance.

Figure 3.2: Target values and actual container throughput of inland ports and seaports with yard cranes (RTG, RMG and SC)



Source: Authors' calculations

Note: The container terminals and ports are ranked from the most to the least efficient (from left to right), according to their CRS super efficiency measures. The black line depicts the annual container throughput in 2014, while the vertical bars show the percentage of the increase of the output, in order for the port to become efficient. The displayed upper boundary percentage is limited to 200%.

The average score of all ports in terms of CRS efficiency is relatively low at 0.676. This result is probably due to the fact that both inland ports and seaports are included in the sample, and the presence of some outliers (very efficient ports) that cause the others to appear very inefficient. This hypothesis is confirmed by the relatively high VRS score (0.852).

Table 3.4 Ports' benchmark times in DEA-CCR and DEA-BCS models (Category 1)

	Country	CRS peer	VRS peer
Bitung	Indonesia	0	1
Pontianak	Indonesia	0	10
Jambi Port	Indonesia	0	2
Jakarta International Container Terminal	Indonesia	2	2
Tanjung Perak Port	Indonesia	20	10
Berlian Jasa Terminal	Indonesia	3	2
Kuantan Port	Malaysia	0	1
Penang Port	Malaysia	1	1
West Port Container Terminal (Port Klang)	Malaysia	15	12
Phnom Penh Autonomous Port	Cambodia	0	1
Sihanoukville Autonomous Port	Cambodia	0	10
Thai Laemchabang Terminal Co., Ltd. and Hutchison Laemchabang Terminal Limited	Thailand	1	1
Đình Vũ	Vietnam	17	7
Tan Cang-Cai Mep International Terminal	Vietnam	17	12

Source: Authors' calculations

In 2014, the ports in the first category had a total container throughput of 38 million TEUs. If they had operated efficiently under the CRS assumption (producing their CRS efficiency targets), they would have been able to increase the container throughput by 20.17% (7.7 million TEUs). On the other hand, if all ports had been VRS efficient, they would have handled 10.83% more containers (4.1 million TEUs).

Regarding the number of times that a port is a benchmark for another DMU, Table 3.4 shows that under the CRS assumption, Tanjung Perak, Dinh Vu, Tan Cang-Cai Mep, Berlian Jasa Terminal and West (Port Klang) are peers for other inefficient ports. However, under VRS, the port of Pontianak becomes a peer for a considerable number of terminals.

In this category, most of the ports are from Indonesia and Vietnam. Indonesian ports have better CRS and VRS scores. On average, the ports in these two countries have similar scale efficiencies (0.770). Malaysia and Thailand have the most efficient ports, but it is not possible to make any general conclusions because there are very few ports from these countries in the sample. As expected, seaports have better efficiency scores than inland ports. The former operate on a better scale. However, in terms of VRS efficiency, the performances of both types of ports are almost identical.

Table 3.5: Average CRS, VRS and SC scores per country (Category 1)

	Number of ports	CRS Average	VRS average	Scale average
Indonesia	14	0.68	0.89	0.77
Vietnam	11	0.59	0.77	0.77
Malaysia	3	0.97	0.97	1.00
Cambodia	2	0.74	1.00	0.74
Thailand	2	0.86	0.92	0.93
Myanmar	1	0.67	0.68	1.00
Philippines	2	0.67	0.75	0.86
Sea Ports	25	0.74	0.85	0.86
Inland Ports	12	0.55	0.86	0.67

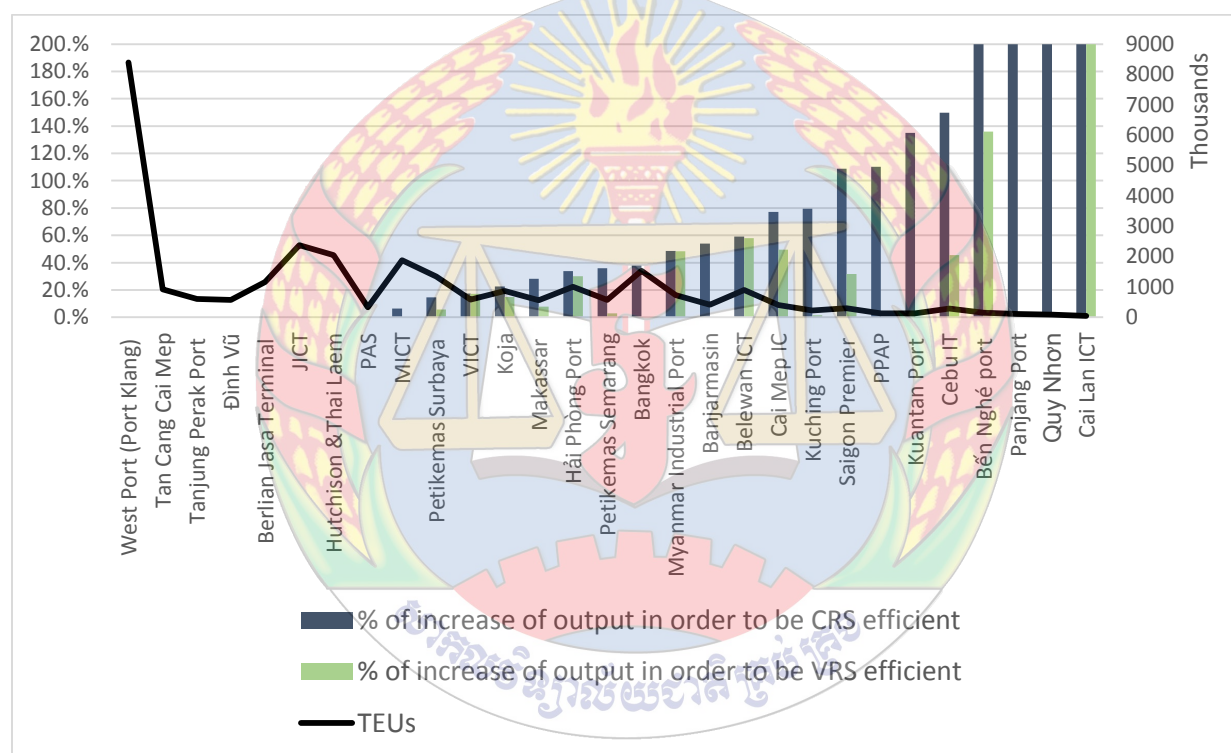
Source: Authors' calculations

3.5.2. Category 2 (Inland and Sea Ports with RTGC and Forklift systems)

Among the 29 inland ports and seaports operated by RTGs and FTs in container yards, eight are found to be efficient. According to super-efficiency measures, the best performance is achieved by West (Port Klang), which also has the largest volume of container throughput in 2014, i.e., 16.3 million TEUs. Although Sihanoukville Autonomous Port (PAS) has only 330,000 TEUs, it also appears to be efficient. The Vietnamese inland port Đình Vũ is again a benchmark. The most inefficient ports are Bến Nghé, Panjang, Quy Nhơn, and Cai Lan ICT. Belawan ICT and Hai Phong are the only ports operating under decreasing returns to scale.

In 2014, the total container throughput of the ports in Category 2 was 28.6 million TEUs. If all of them were operating on the efficiency frontier, they would attract 21.36% more of container volume for their throughput (6.1 million additional TEUs). Regarding the efficiency under VRS, the total loss in terms of transported containers is 8.82%. Most of the ports have a good scale, and on average, the scale efficiency is 0.798. Detailed results regarding this category are presented in Appendix 3.C.

Figure 3.3: Target values and actual container throughput of inland ports and sea ports with RTGs and FTs systems (Category 2)



Source: Authors' calculations

Note: The container terminals and ports are ranked from the most to the least efficient (from left to right), according to their CRS super efficiency measures. The black line depicts the annual container throughput in 2014, while the vertical bars show the percentage of the increase of the output, in order for the port to become efficient. The displayed upper boundary percentage is limited to 200%.

Table 3.6 depicts how many times a port appears to be a benchmark in the DEA-CCR and DEA-BCC models. Under the assumption of CRS, Tan Cang-Cai Mep is a benchmark 15 times, Đình Vũ is a benchmark 14 times, and West (Port Klang) and Tanjung Perak are benchmarks 13

times. In the DEA-BCC model, very few ports differ from the others. The first is Kuantan Port (peer to four ports), followed by Phnom Penh Autonomous Port (PPAP) (peer to seven ports). These ports are not CRS efficient. However, when they are compared to similar ports, they appear to be efficient, which means that there are some factors (i.e, structural differences) that do not allow them to be CRS efficient.

Table 3.6 Port's benchmark times in DEA-CCR and DEA-BCC models (Category 2)

Port	Type	Country	CRS peer	VRS peer
Jakarta International Container Terminal	Seaport	Indonesia	2	3
Tanjung Perak Port	Seaport	Indonesia	13	12
Berlian Jasa Terminal	Seaport	Indonesia	3	2
Kuantan Port	Seaport	Malaysia	0	4
West Port Container Terminal (Port Klang)	Seaport	Malaysia	13	8
Phnom Penh Autonomous Port	Inland port	Cambodia	0	7
Sihanoukville Autonomous Port	Seaport	Cambodia	0	10
Thai Laemchabang Terminal Co., Ltd. and Hutchison Laemchabang Terminal Limited	Seaport	Thailand	1	1
Đình Vũ	Inland port	Vietnam	14	3
Quy Nhơn	Seaport	Vietnam	0	1
Tan Cang-Cai Mep International Terminal	Seaport	Vietnam	15	6

Source: Authors' calculations

Regarding the average scores at a country level (Table 3.7), it is observed that Indonesia again has higher scores than Vietnam, and in this specific sample, Indonesian terminals have very good scale efficiencies, with an average of 0.83. In general, seaports have better performances than inland ports, but the difference between the two groups is only 0.06 points. This result means that by excluding the five inland ports that use only a forklift system, the overall performance of the other inland ports has increased.

Table 3.7: Average CRS, VRS and SC scores by country (Category 2)

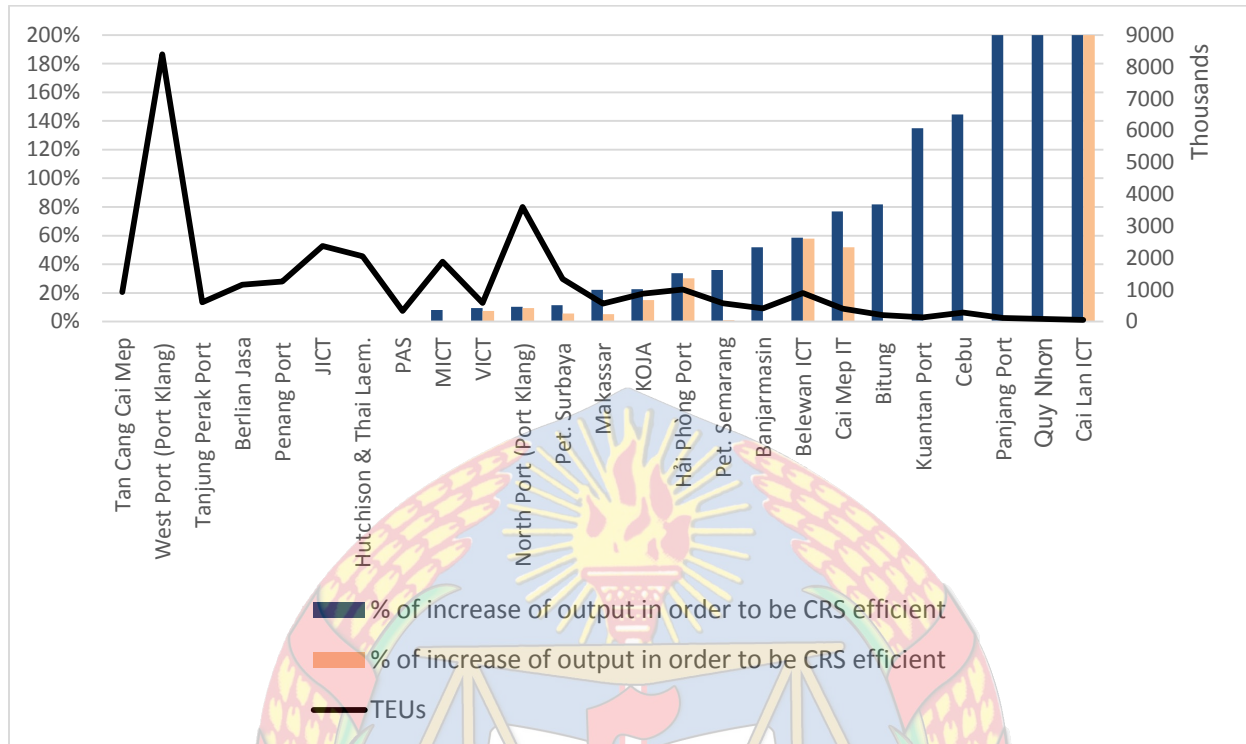
Country	Number of ports	CRS Average	VRS average	Scale average
Indonesia	10	0.77	0.93	0.83
Vietnam	8	0.58	0.73	0.81
Malaysia	3	0.71	1.00	0.71
Cambodia	2	0.74	1.00	0.74
Thailand	2	0.86	1.00	0.86
Myanmar	1	0.67	0.68	1.00
Philippines	2	0.67	0.84	0.76
Total seaports	22	0.72	0.88	0.82
Total inland ports	7	0.61	0.83	0.74

Source: Authors' calculations

3.5.3. Category 3: Seaports/terminals with yard gantry systems and FTs

The third category includes 25 ASEAN sea container port/terminals that operate yard gantry handling systems. Recall that RTGs, RMGs, and SCs are counted as yard gantry systems. The port of Tan Cang-Cai Mep (Vietnam) appears to be the most efficient according to CRS super-efficiency measures, followed by West (Port Klang) (Malaysia) and Tanjung Perak (Indonesia). Cebu, Panjang Port, Quy Nhon, and Cai Lan ICT again appear to be inefficient. The ports in the sample handled 30 million TEUs of container throughput in 2014. If they had operated efficiently, they would have transported 4.7 million additional containers, or 15.36% more. In the case of VRS efficiency, they would have increased their total throughput by 6.67% (around 2 million additional TEUs). The DEA outcomes for this category can be found in Appendix 3.D.

Figure 3.4 Target values and actual container throughput of seaports with yard gantry systems and FTs (Category 3)



Source: Authors' calculations

Note: The container terminals and ports are ranked from the most to the least efficient (from left to right), according to their CRS super efficiency measures. The black line depicts the annual container throughput in 2014, while the vertical bars show the percentage of the increase of the output, in order for the port to become efficient. The displayed upper boundary percentage is limited to 200%.

Tanjung Perak is a peer 14 times (Table 3.8), followed by West (Port Klang) and Tan Cang-Cai Mep, in the case of the DEA-CCR output model. In terms of VRS efficiency, we see that, despite the fact that Bitung is not CRS efficient, it is VRS efficient and is a benchmark for two other ports. On the other hand, regarding CRS efficiency measures, PAS is a peer for none of the ports, but under VRS assumption, it is a benchmark for seven units.

Table 3.8: Ports' benchmark times in DEA-CCR and DEA-BCC models (Category 3)

Port	Country	CRS	VRS
Bitung	Indonesia	0	2
JICT	Indonesia	2	1
Tanjung Perak Port	Indonesia	14	7
Berlian Jasa	Indonesia	1	1
Penang Port	Malaysia	1	1
West Port (Port Klang)	Malaysia	13	8
PAS	Cambodia	0	7
Thai Laemchabang Terminal Co., Ltd. and Hutchison Laemchabang Terminal Limited	Thailand	1	1
Tan Cang Cai Mep	Vietnam	11	6

Source: Authors' calculations

Among the countries with more than two seaports with RTGs and forklift systems in the sample, Malaysia has the highest average CRS score, followed by Indonesia and Vietnam (Table 3.9). In terms of scale efficiency, Malaysian ports have the best performance.

Table 3.9: Average CRS, VRS and SC scores by country (Category 3)

Country	Number of ports	CRS Average	VRS average	Scale average
Indonesia	11	0.76	0.94	0.81
Vietnam	6	0.59	0.75	0.78
Malaysia	4	0.83	0.98	0.85
Cambodia	1	1.00	1.00	1.00
Thailand	1	1.00	1.00	1.00
Philippines	2	0.67	0.96	0.70

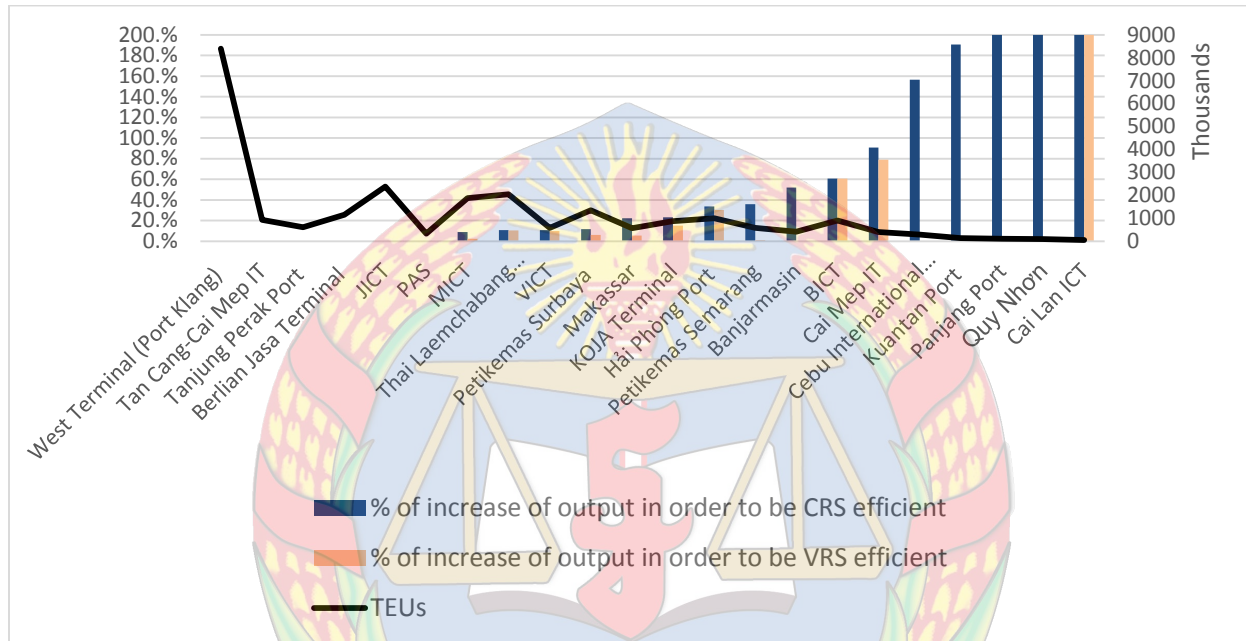
Source: Authors' calculations

3.5.4. Category 4: Seaports/terminals with RTGs and FTs

Category 4 includes 22 ASEAN seaports/terminals that have RTG and FT handling systems in the yards. Because a small number of ports use such systems, we excluded one input. The most correlated input was found to be the number of trucks. Therefore, the following inputs were used

for the DEA models: depth at berth (meters), container yard size (m²), length of quays (meters), number of quay cranes, number of RTGs, and number of FTs. The DEA efficiency score for each port belonging to this category are illustrated in Appendix 3.E.

Figure 3.5: Target values and actual container throughput of seaports with RTGs and FTs
(Category 4)



Source: Authors' calculations

Note: The container terminals and ports are ranked from the most to the least efficient (from left to right), according to their CRS super efficiency measures. The black line depicts the annual container throughput in 2014, while the vertical bars show the percentage of the increase of the output, in order for the port to become efficient. The displayed upper boundary percentage is limited to 200%.

Figure 3.5 shows that the most efficient port in terms of CRS super-efficiency measures is West (Port Klang) (Malaysia), followed by Tan Cang-Cai Mep (Vietnam), Tanjung Perak (Indonesia), Berlian Jasa (Indonesia), JICT (Indonesia), and PAS (Cambodia). The least efficient terminals, which must increase by more than 100% to become CRS efficient, are the following: Cebu (Philippines), Kuantan (Malaysia), Panjang Port (Indonesia), Quy Nhon (Vietnam), and Cai Lan ICT (Vietnam). However, it should be emphasized that all of these CRS inefficient ports, excluding Cai Lan ICT, are VRS efficient. This result means that these ports are somehow different

from the others (i.e., they have a significant difference in the distribution of the inputs). All ports except Hai Phong are operating under increasing returns to scale. By removing both the input “trucks” and the seaports that are not using RTG and FT systems, it is clear that Belawan ICT operates under increasing returns to scale (Hirschman).

Table 3.10: Ports’ benchmark times in DEA-CCR and DEA-BCC models (Category 4)

Port	Type	Country	Peer CRS	Peer VRS
JICT	Seaport	Indonesia	4	0
Tanjung Perak Port	Seaport	Indonesia	9	10
Berlian Jasa Terminal	Seaport	Indonesia	1	1
West Container Terminal (Port Klang)	Seaport	Malaysia	14	11
PAS	Seaport	Cambodia	3	10
Tan Cang-Cai Mep International Terminal	Seaport	Vietnam	5	4

Source: Authors’ calculations

West (Port Klang) appears as a benchmark for 14 ports in the DEA-CCR model. In addition, as we have already seen, this port is the most efficient in terms of CRS super-efficiency measures. Tanjung Perak is also a benchmark many times (nine times), whereas JICT and Berlian Jasa have a very interesting result in that the former is not a benchmark for any of the units in the sample and the latter is a benchmark for only one. These two terminals probably have significant structural differences from the others.

Table 3.11: Average CRS, VRS and SC scores by country (Category 4)

Country	Number of	CRS Average	VRS average	Scale average
Indonesia	10	0.779	0.937	0.840
Vietnam	6	0.572	0.724	0.805
Malaysia	2	0.672	1.000	0.672
Cambodia	1	1.000	1.000	1.000
Thailand	1	0.903	0.906	0.997
Philippines	2	0.654	0.989	0.664

Source: Authors’ calculations

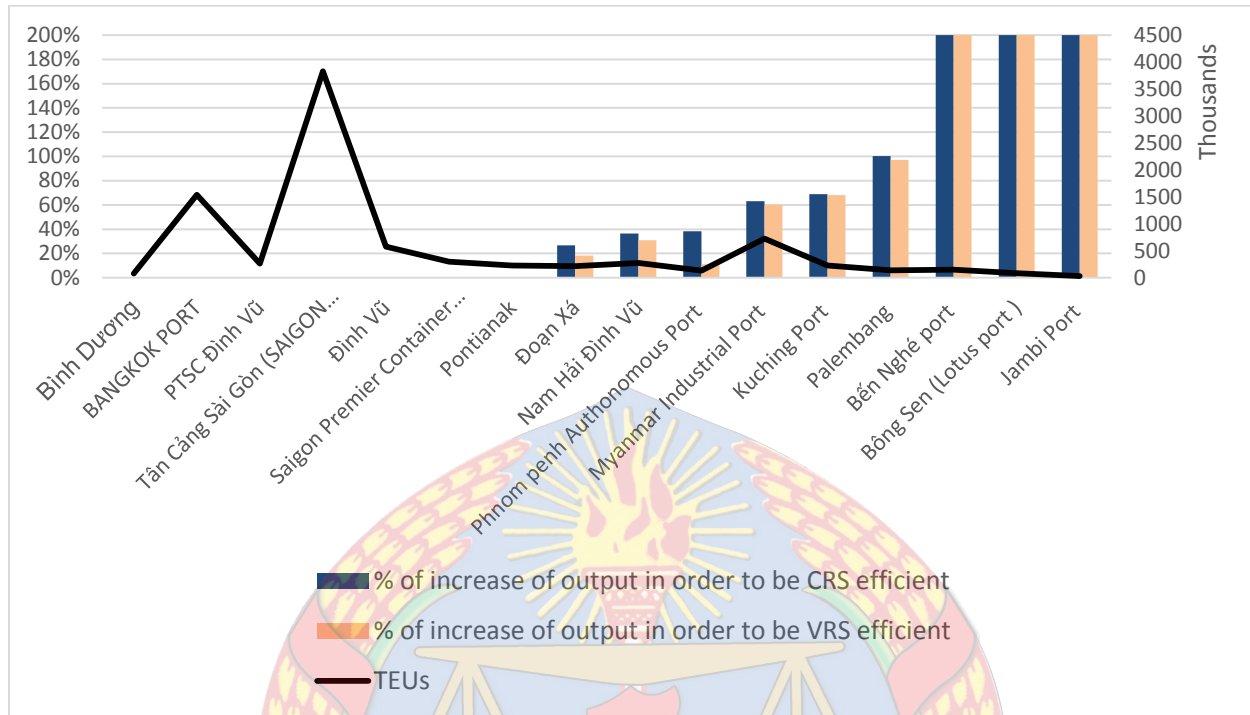
In the sample, most of the ports are Indonesian and Vietnamese. According to the results depicted in Table 3.11, Indonesian ports have much higher scores in terms of CRS and VRS efficiency. Regarding scale measurements, the difference between the two groups is not significant.

3.5.5. Category 5: Inland ports, regardless of their yard handling equipment

In this category, all inland ports have been included regardless of their handling equipment in the container yard. As there are 16 container terminals in this category, only four inputs are selected, according to the rule of thumb. We have chosen the least correlated inputs, which are maximum depth at berth (m), container yard size (m²), length of quays (m), and number of quay cranes. Appendix 3.F illustrates the efficiency scores of all ports belonging to Category 5.

Figure 3.5 depicts the necessary percentage increase in output for each of the ports to reach its target values and the actual container throughput in 2014. Seven ports are efficient, and, according to the CRS super-efficiency measure, the most efficient inland port is Binh Duong, followed by Bangkok, PTSC Đình Vũ, Saigon New Port, and Đình Vũ, and the most inefficient ones are Bến Nghé Port, Bông Sen (Lotus Port), and Jambi Port. The total container throughput in 2014 of all ports in the sample was almost 8.8 million TEUs. If all of them were on the CRS efficiency frontier, they would have increased their productivity by 20%. In the case of VRS efficiency, these ports would have been able to handle 18.68% more container volume.

Figure 3.6 Target values and actual container throughput of inland ports regardless of yard crane system (with FTs and/or yard cranes) (Category 5)



Source: Authors' calculations

Note: The container terminals and ports are ranked from the most to the least efficient (from left to right), according to their CRS super efficiency measures. The black line depicts the annual container throughput in 2014, while the vertical bars show the percentage of the increase of the output, in order for the port to become efficient. The displayed upper boundary percentage is limited to 200%.

It should be highlighted that, by removing some input indicators, the efficiency of the port of Đình Vũ is reduced. In the first and second categories, this port was the only efficient inland port. In this group of inland ports, Đình Vũ appears as efficient, even though in terms of super-efficiency, it is ranked 5th.

Table 3.12: Table 12 Ports' benchmark times in DEA-CCR and DEA-BCC models (Category 5)

Ports/terminals	Country	CRS peer	VRS peer
Pontianak	Indonesia	1	5
Bangkok Port	Thailand	6	5
Saigon Premier Container Terminal	Vietnam	3	3
Đình Vũ	Vietnam	6	4
PTSC Đình Vũ	Vietnam	3	6
Bình Dương	Vietnam	4	5
Saigon New Port	Vietnam	1	2

Source: Authors' calculations

Table 3.12 shows that the ports of Bangkok and Đình Vũ were benchmarks six times, followed by the port of Bình Dương (four times). Regarding VRS efficiency, the port of PTSC Đình Vũ is still a benchmark for six other ports.

Table 3.13: Average CRS, VRS and SC scores per country (Category 5)

Country	Number of ports	CRS Average	VRS average	Scale average
Indonesia	3	0.57	0.58	0.96
Vietnam	9	0.78	0.79	0.99
Malaysia	1	0.59	0.59	1.00
Cambodia	1	0.72	0.90	0.80
Thailand	1	1.00	1.00	1.00
Myanmar	1	0.61	0.62	0.98

Source: Authors' calculations

Vietnamese terminals have very good efficiency scores and are the most numerous in this category (nine ports). Contrary to the results of the previous group, Vietnamese inland ports seem to be more efficient than Indonesian inland ports.

3.5.6. Category 6: Inland ports with yard gantry systems (including SCs)

There are only 12 inland ports with cranes in the container yard. Therefore, similar to the previous category, it is not recommended to include all seven input categories, and instead, we only include two. Therefore, eight DEA output-oriented CCR models are selected. Appendix 3.G illustrates the DEA efficiency scores of each port in the Category 6.

Table 3.14: Ranking of inland ports with cranes in the storage yard according to DEA-CCR output-oriented models with two inputs

Port	Country	TEUs	No of times the port appears efficient	Depth & CY size	Depth & length	Depth & quay cranes	CY size & length	CY size & forklifts	Length & yard cranes	Length & forklifts	Length & trucks
Palenbang	Indonesia	137,685	0	8	6	10	7	7	6	6	6
Pontianak	Indonesia	227,130	2	1	4	6	1	2	4	5	4
Jambi Port	Indonesia	29,379	0	9	12	12	8	8	12	12	12
Kuching Port	Malaysia	227,600	0	10	9	5	10	10	9	8	9
Myanmar Industrial	Myanmar	728,000	0	7	7	7	9	9	7	9	10
PPAP	Cambodia	133,666	0	6	8	8	4	4	8	7	8
Bangkok Port	Thailand	1,356,106	2	1	3	3	3	3	3	4	3
Saigon Premier	Vietnam	301,382	4	1	5	4	1	1	5	1	5
Đinh Vũ	Vietnam	574,635	5	5	2	1	5	5	1	1	1
Saigon New Port	Vietnam	3,827,115	7	1	1	1	6	6	1	1	1
Bến Nghé Port	Vietnam	148,306	0	12	11	9	12	12	11	10	7
Bông Sen (Lotus) Port	Vietnam	84,900	0	11	10	11	11	11	10	11	11
Total		7,755,904									
Average CRS target value		13,087,662									
Average % increase of output in order to be CRS efficient		64.5%									

Source: Authors' calculations

Table 3.14 gives the ranking of the ports according to some combination of the seven inputs. Saigon New Port is efficient seven times, and Đình Vũ is a benchmark five times. The terminals of Pontianak (Indonesia), Bangkok (Thailand), and Saigon Premier are also efficient in some of the DEA models. In 2014, the total container throughput of the ports in the sample was 7.95 million TEUs. On average, if all of the ports were operating efficiently, they should have been able to increase their container throughput by around 64.5% of volume. However, it should be emphasized that, for each DEA model, only two indicators are taken, and therefore, in order to have more reliable results, the sample size must be increased. In addition, this high percentage may be due to the presence of outlier(s) or super-efficient port(s) that make the other ones appear very inefficient.

Most inland ports operated by yard gantry systems in the sample are in Vietnam, but there are no additional conclusions to be made due to the small size of the sample and the small number of inputs used for the different DEA models (Table 3.14).

3.6. PCA and cluster analysis, Category 1

A complementary method to double check the DEA outcomes and to highlight groups of similar ports is the Cluster Analysis. Such an approach was used for a sample of 77 ports by Wu et al. (2010). Prior to the cluster analysis a Principle Component Analysis (PCA) is conducted. PCA was developed by Pearson (1901). This method reduces the dimensionality of a data set in which there is a large number of interrelated variables, while retaining as much as possible of the variation. Based on the prior PCA, a Hierarchical Agglomerative Clustering Analysis was conducted by using the method of Ward Jr (1963) to identify the different clusters.

3.6.1. Principle Component Analysis for Category 1

Since the first category is the biggest one (37 ports), we have decided to apply PCA and Cluster Analysis approach on this particular sub-sample of ASEAN ports. In the DEA output oriented models that have been applied in this chapter, there is only one output, the Annual

Container Throughput in 2014 in TEUs. Therefore, for the PCA analysis we use simple productivity ratios, the Annual Container Throughput divided by the input variables (Max depth at berth, Size of the container Yard, Length of the quays, Number of Quay Cranes, Number of Yard cranes (MRGC, SC or RTGC), Number of Forklifts and Number of Trucks). As supplementary variables we use the location of the port (seaport or inland port) and the country where it is situated. Table 3.15 depicts the active and supplementary variables in this study.

Table 3.15. Variables used for the PCA and Cluster Analysis

Name of the Variable	Role of the variable	Description
TEU/depth	Active	Container Throughput in 2014 (TEU) divided by the maximum depth at berth (m)
TEU/Size_CY	Active	Container Throughput in 2014 (TEU) divided by the size of the container yard in m ²
TEU/Length_quays	Active	Container Throughput in 2014 (TEU) divided by length of the quays (m)
TEU/Cranes_quay	Active	Container Throughput in 2014 (TEU) divided by the number of quay cranes
TEU/Cranes_CY	Active	Container Throughput in 2014 (TEU) divided by the number of yard cranes which includes MRGC, SC and RTGC
TEU/Forklifts	Active	Container Throughput in 2014 (TEU) divided by the number of forklifts
TEU/Trucks	Active	Container Throughput in 2014 (TEU) divided by the number of trucks
Type	Supplementary	Seaport or inland port
Country	Supplementary	The country where is located the container port/terminal
TEU	Supplementary	Container Throughput in 2014 (TEU)

Source: Authors' calculations

Table 3.16. depicts the correlation between active variables. Not surprisingly, there is a strong correlation between TEU/ Length_quays and TEU/Cranes_quay. It is interesting to highlight the high level of correlation between TEU/depth and TEU/Length_quays as well as between TEU/Length_quays and TEU/Trucks.

Table 3.16. Pearson's correlation matrix of the variables used for the PCA and Cluster Analysis

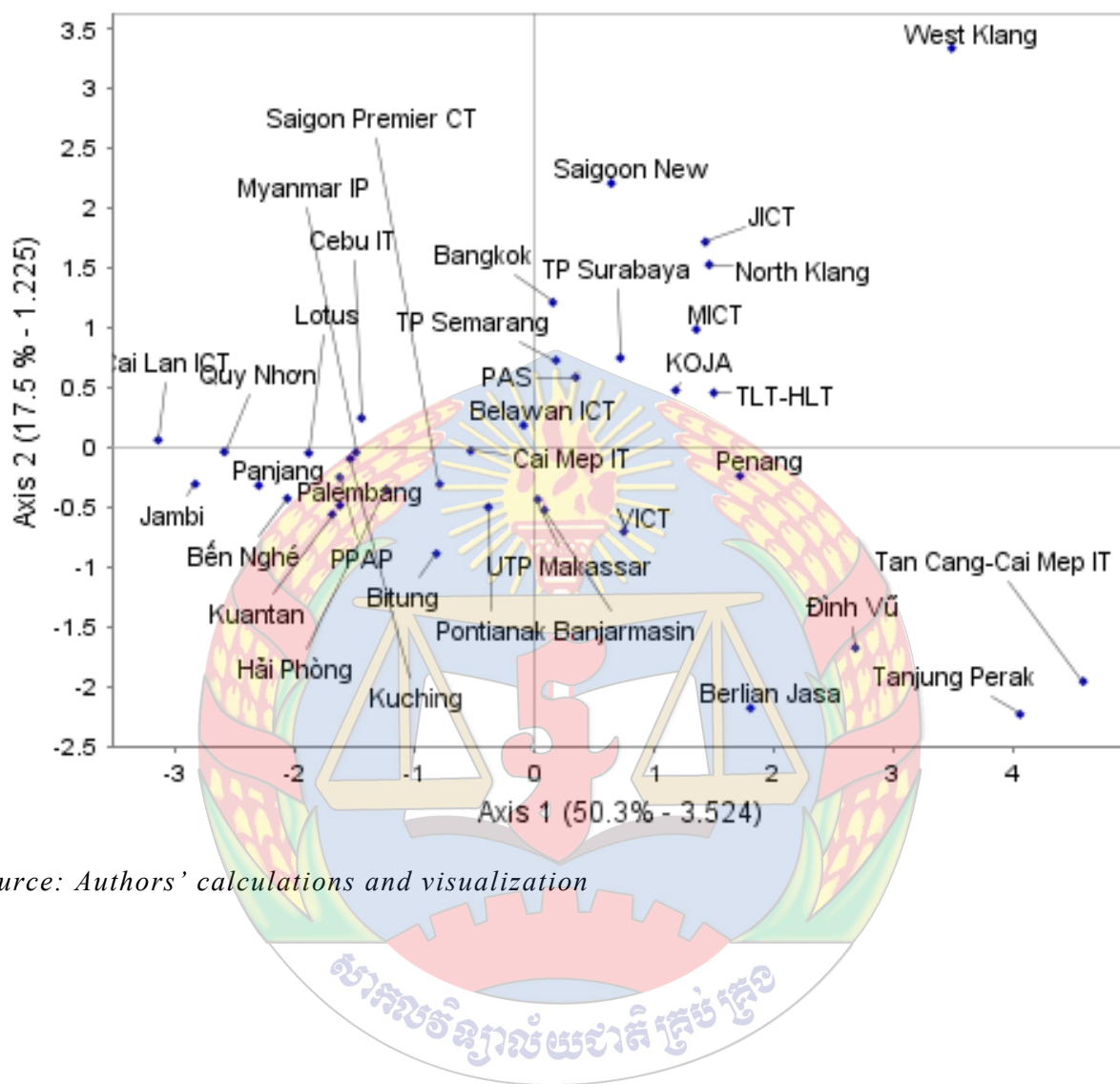
	TEU/ depth	TEU/Size CY	TEU/Length quays	TEU/Cranes quay	TEU/Cranes CY	TEU/Forklifts	TEU/Trucks
TEU/depth	1.000						
TEU/Size_CY	0.103	1.000					
TEU/Length_quays	0.633	0.421	1.000				
TEU/Cranes_quay	0.549	0.258	0.688	1.000			
TEU/Cranes_CY	0.190	0.379	0.488	0.229	1.000		
TEU/Forklifts	0.208	0.431	0.421	0.350	0.097	1.000	
TEU/Trucks	0.219	0.555	0.642	0.512	0.637	0.524	1.000

Source: Authors' calculations

First we study the inertia of the principle components by analyzing the inertia intercepted by the factorial axe. Appendix 3.H shows the Eigenvalues associated with each component, the percentage of explained variance and the cumulated percentage. Following the Kaiser's criterion, we have decided to retain the first two components. Their cumulative percentage of explained variance is 67.8 %. The first axis explains 50.3% of the variance, while the second one accounts for only 17.5%.

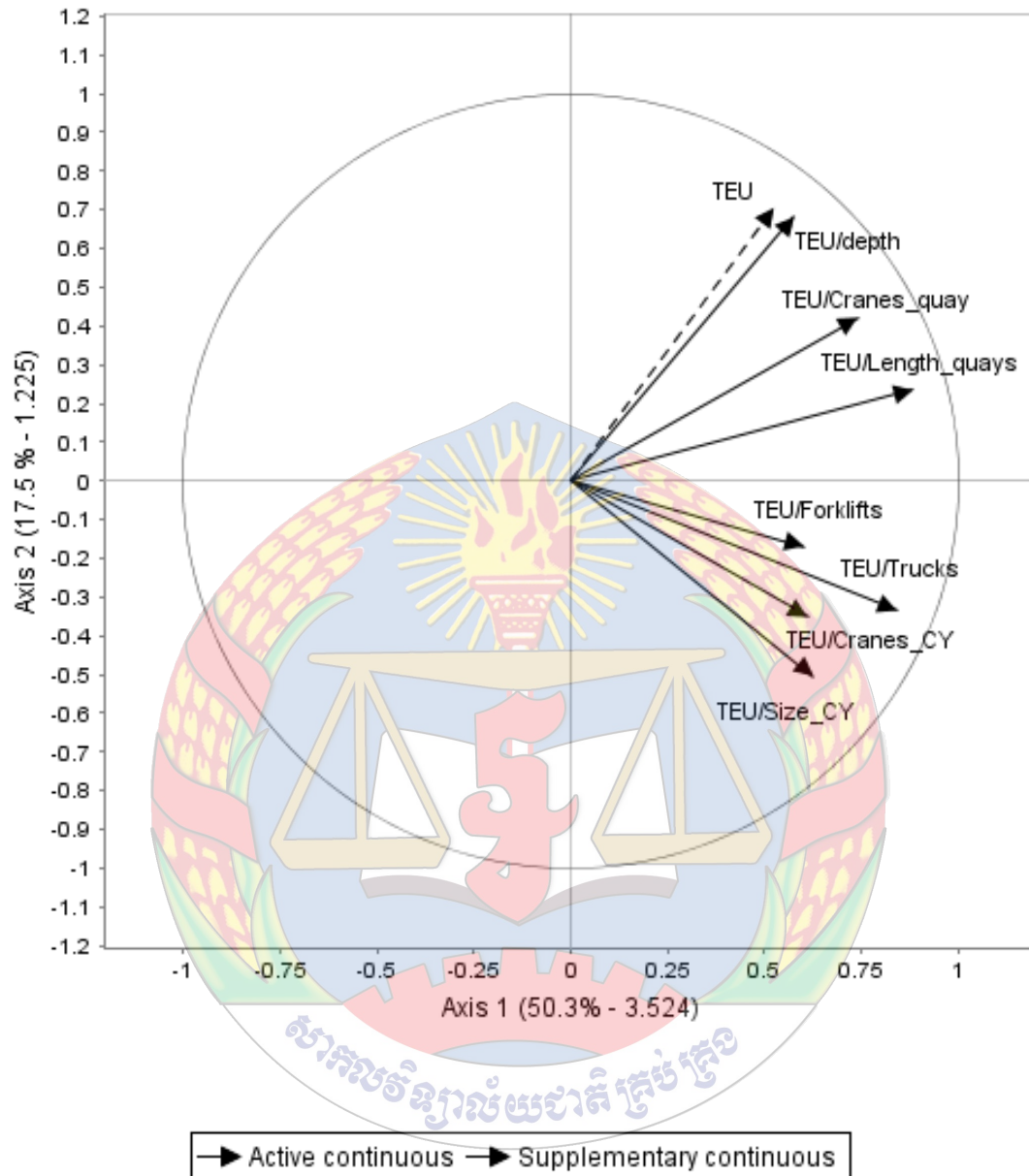
Next we evaluate the contribution and correlation of active variables to each of the two retained components. As shown in Appendix 3.I. TEU/Length_quays and TEU/Trucks, TEU/Cranes_quay have a very strong correlation with the first component and these variables contribute 50.23% to the first axis. TEU/depth and TEU/Size_CY have a strong positive correlation with the second axis and their cumulative contribution is 59.09%. It should be highlighted that the variable TEU/Size_CY has a positive correlation with the first axis (0.63) and negative correlation (-0.51) with the second axis. Therefore, we can conclude that on the basis of the PCA outcomes, ASEAN ports and terminals can be categorized according to the operational productivity (handled containers per meter of the quay, per truck and per quay crane) and the port's size and its location (handled container per meter of depth at berth and per m² of the container yard).

Figure 3.7. Graphical representation of individuals (ports) according to the two axis



Source: Authors' calculations and visualization

Figure 3.8. Graphical representation of active and supplementary continuous variables

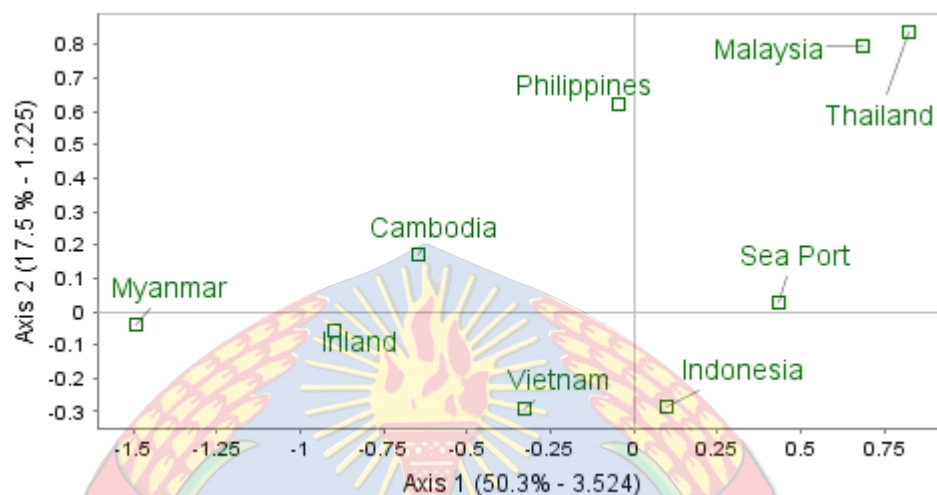


Source: Authors' calculations and visualization

Figure 3.7 and Figure 3.8 show that West Port Container Terminal (Port Klang) has good productivity in terms of handled containers per meter of depth at berth, per quay crane and also a high level of container throughput. Ports such as Tan Cang-Cai Mep, Đình Vũ and Tanjung Perak have good productivity in terms of containers handled per quay crane, per meter of their container

yards and per truck. Ports, situated on the left side or in the center of the 0 vertical line in Figure 3.7, have low efficiency ratios.

Figure 3.9. Graphical representation of the supplementary categorical variables related to the Country and type of ports (seaport or inland port)



Source: Authors' calculations and visualization

At the country level, we could see that the most inefficient ports are situated in Myanmar and Cambodia (Figure 3.9). Countries that have around the average productive efficiency are Philippines, Vietnam and Indonesia. Highly efficient ports are situated in Thailand and Malaysia.

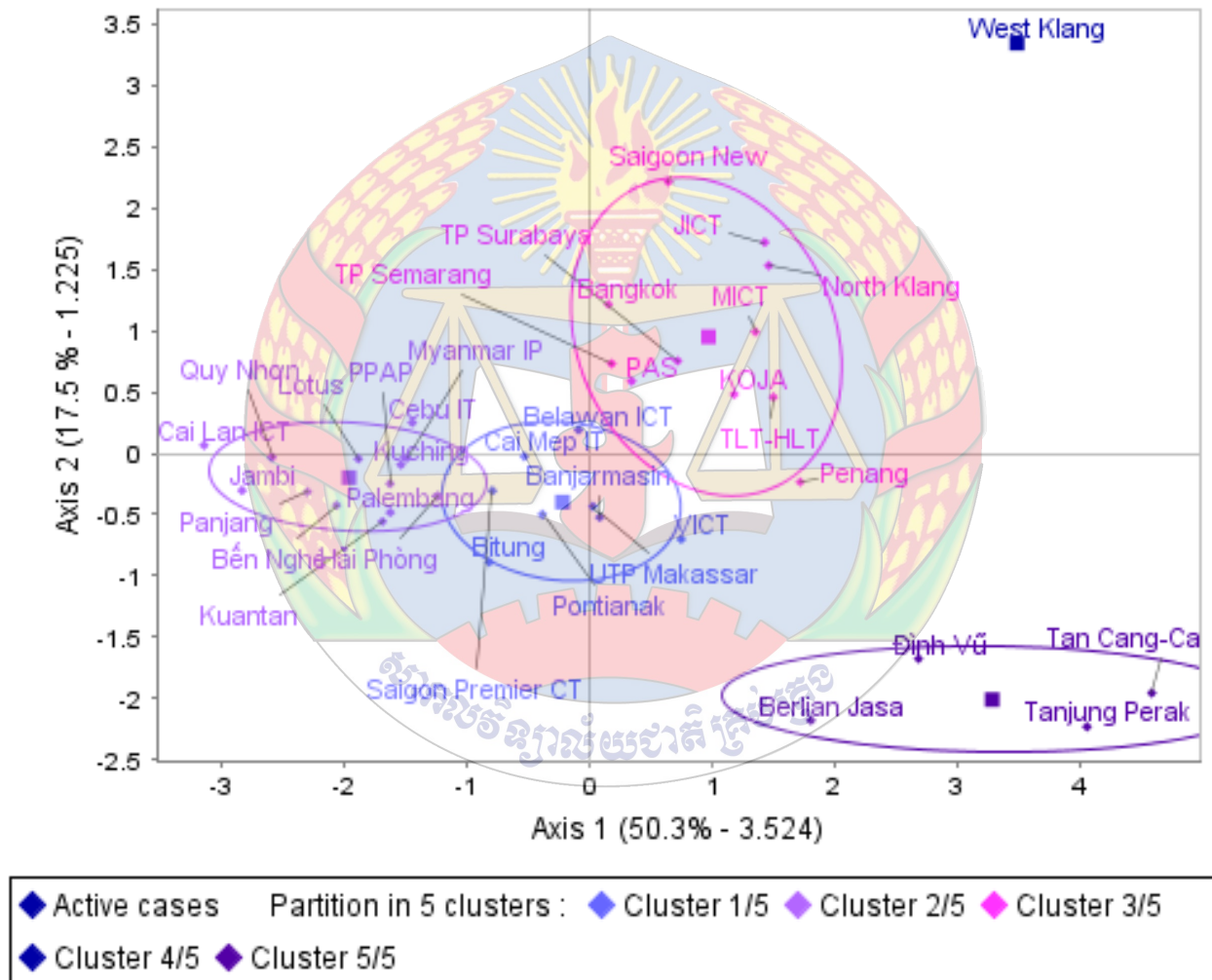
3.6.2. Cluster Analysis

The objective of cluster analysis is to classify the ports on the basis of the prior PCA results. Since we use simple productivity ratios (TEU divided by a variable related to the infrastructure of the port), we expect that efficient ports identified by DEA methodology would form separate clusters of ports. The ports that were found to be inefficient in the DEA should also form clusters.

Appendix 3.J depicts some metrics related to the optimal number of clusters. The objective is to have clusters that are clearly distinguished (having high inter-cluster inertia). The Calinski-Harabasz criterion (or pseudo F) and The Davies-Bouldin index suggest that the optimum number

of clusters is five or six. Considering the size of the sample and the small difference between the intra-cluster and inter-cluster inertia in the cases of five and six clusters, as well as the fact that the percentage of explained inertia increases by only 2.48% when we increase the number of clusters from five to six, it is more appropriate to retain five clusters. Appendix 3.K shows the Hierarchical tree (Dendrogram). By choosing to retain five clusters, we explain 88.2% of the total variability.

Figure 3.10. Graphical representation of the five clusters on the first two PCA axes



Source: Authors' calculations and visualization

As we can see in Figure 3.10, cluster 1 is situated in the barycenter of the graph. It is a cluster of ports with average productivity ratios which includes two inland ports and 6 seaports. Cluster 2

is situated on the left side on the first axis. In this cluster, ports have low productivity ratios. In the third cluster, there are mainly deep-sea large ports with higher than average productivity ratios. An outlier in the sample is West Port Container Terminal (Port Klang), it forms a cluster by itself. Therefore, it seems that this terminal is considerably different than the others. Moreover, its productive ratios in terms of handled container per meter of depth at berth and per m² of the container yard are significantly higher than the other ports in the sample. The fifth cluster includes ports that have the highest productivity ratios in terms of handled containers per meter of the quay, per truck and per quay crane. With the exception of Đình Vũ port, all individuals in this cluster are seaports.

3.6.3. Comparing the results of DEA and Cluster Analysis

Combining Cluster analysis with DEA allows researchers to define more precisely ports of reference (benchmarks). For instance, often DEA gives a couple of ports as benchmarks to one single port. In addition, Clustering analysis can identify outliers in the sample which will form very small clusters.

The first cluster includes eight ports. As we can see their productivity ratios with the exception of TEU/Forklifts and TEU/depth as well as their DEA scores are very close to the average values of all ports in the sample (Table 3.17.).

Table 3.17. Cluster 1 descriptive statistics of the active variables (Cluster Analysis) and the DEA results

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
TEU/Trucks	17219.70	14872.70	3279.64	7808.83	0.95	0.17
TEU/Size_CY	4.99	4.85	1.72	6.01	0.07	0.47
TEU/Cranes_CY	40408.10	40684.10	12561.50	24151.60	-0.04	0.49
TEU/Cranes_quay	68691.80	75147.20	11466.80	46731.80	-0.44	0.33
TEU/Length_quays	699.16	796.76	177.40	481.81	-0.64	0.26
TEU/Forklifts	59175.50	129907.00	39548.10	261838.00	-0.85	0.20
TEU/depth	44062.30	80291.30	19940.00	91641.50	-1.25	0.11
DEA CRS scores	0.65	0.68	0.12	0.29	N/A	N/A
DEA VRS scores	0.84	0.85	0.16	0.22	N/A	N/A
DEA SE scores	0.80	0.80	0.17	0.26	N/A	N/A
DEA Super CRS scores	1.59	2.09	0.30	2.19	N/A	N/A

Source: Authors' calculations

Appendix 3.L provides individual DEA scores about all ports belonging to Cluster 1. Results show that for these ports, a clear peer is the Vietnam International Container Terminal which has the best scale efficiency. This cluster includes mainly small ports with annual throughput of around 500,000 TEU.

The second identified cluster is the biggest one, which includes 13 ports and terminals. We can clearly see that the productivity ratios as well as the DEA scores are considerably lower than the mean values⁶⁶.

⁶⁶ ...except for DEA Super Efficiency scores. Higher Super efficiency score indicates an inefficient port.

Table 3.18. Cluster 2 descriptive statistics of the active variables (Cluster Analysis) and the DEA results

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
TEU/Forklifts	10243.10	129907.00	10582.80	261838.00	-2.02	0.02
TEU/Size_CY	1.60	4.85	0.88	6.01	-2.39	0.01
TEU/Cranes_CY	27390.70	40684.10	15997.20	24151.60	-2.43	0.01
TEU/depth	24011.80	80291.30	27191.60	91641.50	-2.71	0.00
TEU/Trucks	7765.10	14872.70	3285.44	7808.83	-4.02	0.00
TEU/Cranes_quay	29282.00	75147.20	16181.20	46731.80	-4.33	0.00
TEU/Length_quays	287.82	796.76	153.00	481.81	-4.42	0.00
DEA CRS scores	0.37	0.68	0.20	0.29	N/A	N/A
DEA VRS scores	0.73	0.85	0.31	0.22	N/A	N/A
DEA SE scores	0.60	0.80	0.31	0.26	N/A	N/A
DEA Super CRS scores	3.87	2.09	2.97	2.19	N/A	N/A

Source: Authors' calculations

Appendix 3.M. indicates that DEA gives the same outcomes (DEA scores are lower than the average) and as a port of reference for this cluster is the Vietnamese port of Hải Phòng. However, this port has an annual container throughput of 1 million TEU and operates under decreasing returns to scale. In general, all ports except Hải Phòng have an annual container throughput of around 150,000 TEU. Thus, we should consider a feasible benchmark (similar port) for the other ports in the cluster. The Myanmar Port is the second most efficient port in this cluster and could be a benchmark for the others.

The third cluster includes 11 ports and the large majority (nine) are seaports. As we can see in Table 3.19, all productive ratios except TEU/Cranes_CY and TEU/Size_CY are lower than the average for the whole sample. These ports in the sample are considerably bigger than the previous two clusters and on average their annual container throughput is around 1.8 million TEU.

Table 3.19. Cluster 3 descriptive statistics of the active variables (Cluster Analysis) and the DEA results

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
TEU/Cranes_quay	122225.00	75147.20	32151.40	46731.80	3.93	0.00
TEU/Length_quays	1119.07	796.76	230.59	481.81	2.63	0.00
TEU/depth	137119.00	80291.30	66641.60	91641.50	2.42	0.01
TEU/Forklifts	203932.00	129907.00	349196.00	261838.00	1.10	0.13
TEU/Trucks	16077.20	14872.70	5430.22	7808.83	0.60	0.27
TEU/Cranes_CY	38311.00	40684.10	6689.67	24151.60	-0.38	0.35
TEU/Size_CY	3.61	4.85	1.18	6.01	-0.80	0.21
DEA CRS scores	0.91	0.68	0.10	0.29	N/A	N/A
DEA VRS scores	0.95	0.85	0.06	0.22	N/A	N/A
DEA SE scores	0.95	0.80	0.07	0.26	N/A	N/A
DEA Super CRS scores	1.06	2.09	0.22	2.19	N/A	N/A

Source: Authors' calculations

In addition, Appendix 3.N shows that the average DEA efficiency scores are higher than the average. There are four ports that were identified as efficient (CRS score = 1) by DEA-CRS model. These ports are TLT-HLT, Jakarta International Container Terminal, Sihanoukville Autonomous Port and Penang port.

In Cluster 4, there is only one individual, West Port Container Terminal (Port Klang). It is clearly an outlier. This terminal is very different than the others. In terms of super efficiency, it is the second most efficient unit (Appendix 3.O).

Cluster 5 includes exclusively efficient ports based on DEA-CRS model. The average productivity ratios except TEU/depth are considerably higher than the average values of the whole sample.

Table 3.20. Cluster 3 descriptive statistics of the active variables (Cluster Analysis) and the DEA results

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
TEU/Size_CY	18.51	4.85	9.86	6.01	4.74	0.00
TEU/Cranes_CY	88263.50	40684.10	35245.00	24151.60	4.12	0.00
TEU/Trucks	29122.40	14872.70	6424.37	7808.83	3.81	0.00
TEU/Length_quays	1403.36	796.76	387.76	481.81	2.63	0.00
TEU/Forklifts	411473.00	129907.00	369154.00	261838.00	2.25	0.01
TEU/Cranes_quay	88293.30	75147.20	39454.90	46731.80	0.59	0.28
TEU/depth	79555.00	80291.30	24690.40	91641.50	-0.02	0.49
DEA CRS scores	1.00	0.68	0.00	0.29	N/A	N/A
DEA VRS scores	1.00	0.85	0.00	0.22	N/A	N/A
DEA SE scores	1.00	0.80	0.00	0.26	N/A	N/A
DEA Super CRS scores	0.57	2.09	0.07	2.19	N/A	N/A

Source: Authors' calculations

Appendix 3.P confirms the high productivity levels of these ports. Actually all of them are found to be efficient in the DEA-CRS model. According to the DEA super-efficiency scores, the most efficient port in this cluster is the port of Tan Cang Cai Mep. This port is also the most efficient port in the category.

By applying PCA and Cluster Analysis on simple productivity ratios (TEU divided by a variable relate to the ports' infrastructure) for the ports in category 1 (Inland ports and seaports with yard gantry systems and SCs), we have similar outcomes as the DEA approach. As we can see DEA and Cluster Analysis are complementary methods that could identify the most efficient ports. As expected, the most efficient ports form separate clusters such as Cluster 4 and Cluster 5. In Cluster 3 there are just four ports that are found to be efficient. None of the ports in Cluster 1 and Cluster 2 have scores of 1 in terms of DEA-CRS efficiency. The fact that West Port Container Terminal (Port Klang) forms an individual cluster might be a sign that this port is an outlier and for a future efficiency analysis, it could be removed from the sample. Overall, we can conclude that the outcomes of the DEA models are reliable for at least this category.

3.7. Discussion

By associating the ports with different categories, the performances of inland ports and seaports as well as the performances of ports with different handling systems in their yards are compared. The results show that ASEAN seaports perform better than ASEAN inland ports. We consider six categories of ports. The first one includes inland and sea terminals with yard cranes (we count all cranes regardless of the type of handling system) and has an average CRS score of 0.676 (Table 3.21) for all ports in this category.

The second category contains all ports using RTGs and FTs as yard handling equipment. It has higher CRS scores (0.696), which means that, on average, the terminals using RTG and FT systems are more efficient than those using other systems, such SC or RMG. The third and the fourth categories excludes all inland ports, and their average CRS, VRS, and scale scores increase as a result (Table 3.21). It indicates that the seaports are more efficient than the inland ports. When three seaports not operated by RTG and FT handling systems, specifically North (Port Klang), Penang, and Bitung, are removed, and when the number of trucks is no longer used as an input, the average efficiency scores decrease. In the fifth category, all inland ports in the sample are compared, and the conclusion is that their efficiency scores are relatively high. By excluding and including ports based on their handling systems, we are able to have some idea about which type of cranes is appropriate. It is interesting to observe that the average scores increases when we include in the sample only ports operating with RTG system. However, regarding the third and fourth categories we have the opposite results. Another important finding is that the average score increases when we have only seaports in the sample rather than inland ports and seaports.

Table 3.21: Average efficiency scores per category

Categories	Average CRS	Average VRS	Average Scale
Category 1 (Inland port and seaports with yard cranes)	0.676	0.852	0.802
Category 2 (Inland port and seaports with RTGs & FTs)	0.696	0.872	0.798
Category 3 (Seaports with yard cranes)	0.741	0.908	0.818
Category 4 (Seaports with RTGs and FTs)	0.717	0.891	0.814
Category 5 (Inland ports)	0.728	0.748	0.971
Category 6 (Inland seaports with yard cranes)	0.522	0.699	0.770

Source: Authors' calculations

The results for the first three categories suggest that Indonesian ports perform better than Vietnamese ports, which is not the case when we compare only inland ports. Malaysian ports are very efficient, and in almost every category they have the best scores. However, it is important to emphasize that there are only four Malaysian ports in the sample in total, and, therefore, no general conclusion is made about the ports in this country.

Comparing the first four categories, we find that the same seaports always have the highest relative efficiency: Tan Cang-Cai Mep, West (Port Klang), Tanjung Perak, Berlian Jasa, Penang Port, JICT, TLT, and PAS. Đình Vũ is the only inland port that has a score of one in the first two categories. Saigon Premier is another inland port that is very close to the efficiency frontier in the first category. Some seaports are also close to the efficiency frontier, such as MICT, North (Port Klang), Pet. Surabaya, KOJA Terminal, and Makassar.

The last two categories only compare inland ports, and it appears that, in addition to Đình Vũ and Saigon Premier, three other ports, Bangkok Port, Binh Dương, and Pontianak, are also benchmarks.

In all categories, most of the ports operate under increasing returns to scale, which means that these ports should increase their inputs in order to become more efficient. Very few are experiencing decreasing returns to scale. Thus, with respect to the DEA models applied in this

study, it can be concluded that the reason for the inefficiency of most of ASEAN ports is their small size.

Finally, in the case of the first Category, by using simple productivity ratios (Annual Container Throughput divided by a given input) as active variables, it was found that the results of Cluster Analysis are consistent with the outcomes of DEA approach. Indeed, both methods are complementary to outline benchmarks for the ports and outliers.

3.8. Limitations

The limits of the traditional nonparametric models are their deterministic (meaning that all deviations from the efficient frontier are considered as inefficiencies, and no noise is allowed) and non-statistical nature; the influence of outliers and extreme values; the lack of parameters for economic interpretation; and unsatisfactory techniques for the introduction of environmental or external variables in the measurement of efficiency (Daraio and Simar, 2007). In addition, it is not realistic to use a hypothetical DMU projected on the efficiency frontier and compare it with real container ports (Lim et al., 2011).

As the DEA method estimates the relative efficiencies of the DMUs, the analysis and results are based on the input and output indicators selected, with the context that the results are only sensible to the set of inputs used. If other indicators were included, such as costs, investments, number of employees, number of ship calls, salaries, time for custom clearance, lifting capacity of gantry cranes, etc., the study could report very different efficiency scores.

A basic requirement for any reliable performance benchmarking exercise is the appropriate definition and selection of homogenous DMUs (Bichou, 2013). In this case, “homogenous DMUs” refers to container ports that use similar technologies (i.e., similar types of quay cranes and yard cranes) or have the same function (i.e., inland port or seaport, domestic or international, or hub or spoke). Due to data unavailability, we were not able to create more specific categories, such as ports using RMGs or ports with SCs, or to categorize the terminals according to the type of quay cranes (i.e., Panamax or Post-Panamax), lifting capacity, etc.

3.9. Conclusions

The relative efficiency DEA analyses conducted in this study imply that ASEAN ports have relatively good scale efficiencies and that most of them could handle even more container volume. There is still a need to analyze in more detail what makes seaports or inland ports efficient. Not surprisingly, this study has identified a significant difference between the performances of inland ports and seaports. In addition, this study finds that the average scale efficiency score increases when removing container terminals using SCs or RMGs.

For future research, more data on port connectivity should be collected, and more ASEAN ports should be included in the sample in order to conduct a complementary analysis at the country level of the relation between the trade performances of the ASEAN states and the performances of their container ports. Prior to the study, the port of Singapore was identified as an outlier and was removed from the sample. The Cluster Analysis for the Category 1, has shown that West Port Container Terminal (Port Klang) is another outlier and for the future analysis, this terminal could be removed. Additional inputs and outputs such as number of workers, salaries, ship calls, CO2 emissions and utilization of renewable energy could also be considered. Such inputs and outputs would allow researchers to analyze other dimensions of the efficiency, i.e. environmental efficiency and allocative efficiency. Additional ports from other regions such as East Asia, Europe, Africa, Americas and Australia could also be considered in order to compare the efficiency of ASEAN and non-ASEAN ports/terminals.

Considering the facts that the competition between container ports and terminals is intensifying and that shipping companies are aiming to realize economies of scale by building bigger vessels, the issue of efficiency has become an important topic. There is a need to increase the availability and reliability of data in order to provide useful recommendations to the ports' managers. The current shipping crisis, which has been further amplified after Hanjin Shipping bankruptcy, highlights the importance of more available and reliable data and cooperation between the main players. Therefore, if shipping companies and container terminals do not increase their capacities to improve their long-term investments and operational costs, the shipping industry will remain in the murky waters of oversupply and uncertainty.

3.10. References

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3.11. Appendices

3.A. Data for the infrastructure and annual container throughput for ASEAN container ports and terminals in 2014.

Port	Type	Country	Throughput (TEUs) in 2014	Max depth at berth	Size of the Container Yard in m ²	Length of quays (berths) in m	Number of Quay cranes (All types) ⁶⁷	No of straddle carriers	No of Mounted Rail Gantry Cranes (MRGC)	No of Rubber Tired Gantry Cranes (RTG)	Number of forklifts ⁶⁸	No of Container trucks, Container Tractors, prime movers
Banjarmasin	Sea Port	Indonesia	413737	9	53300	505	6			11	3	25
Belawan International Container Terminal	Sea Port	Indonesia	900395	11	214708	950	13			25	16	61
Port of Tanjung Priok Terminal	Sea Port	Indonesia	2463908	12	796121	1030	70		9	52	45	
Bitung	Sea Port	Indonesia	200153	11	33000	557	4		4	2	7	11
Unit Terminal Petikemas Makassar	Sea Port	Indonesia	562046	9	114,446	1000	7			11	10	30
Palembang	Inland	Indonesia	137685	9	57357	266	7		4		19	14
Pontianak	Inland	Indonesia	227130	6	47794	295	4		4		18	18
Panjang Port	Sea Port	Indonesia	107546	16	214708	401	7			5	9	13
Taluk Bayur	Sea Port	Indonesia	66942	11	62250	222	5				9	14
Jambi Port	Inland	Indonesia	29379	9	14649	302	4		3		11	6
Jakarta International Container Terminal	Sea Port	Indonesia	2373470	14	547400	2150	13			74	32	139
KOJA Terminal	Sea Port	Indonesia	872511	13	218000	650	7			25	3	48
Tanjung Perak Port	Sea Port	Indonesia	601915	8	34880	320	9			7	1	17
Terminal Petikemas Semarang	Sea Port	Indonesia	575671	10	187168	495	5			19	13	44
Terminal Petikemas Surabaya	Sea Port	Indonesia	1343523	10.5	397000	1450	11			28	27	80
Berlian Jasa Terminal	Sea Port	Indonesia	1158947	9.6	43301	1420	23			15	14	63
Kuantan Port	Sea Port	Malaysia	131000	11.2	59600	600	4			6	3	9

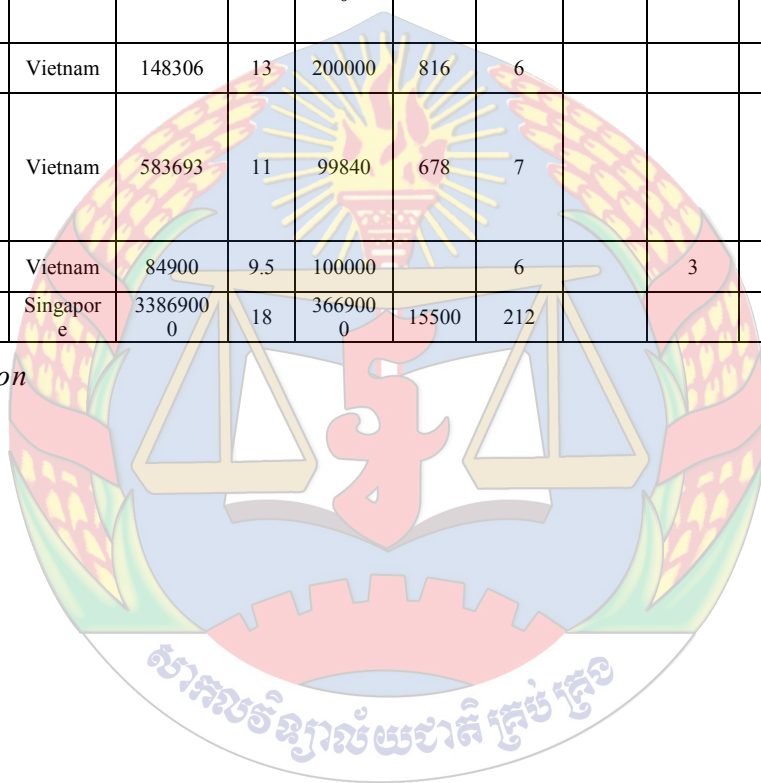
⁶⁷ Panamax, Post Panamax, quay, Gantry cranes, Harbour crane, mobile, HMC, gantry jib crane, slewing crane

⁶⁸ including reachstackers, high stackers, forklifts, and side loaders all sizes, top loader, spreaders

Kuching Port	Inland	Malaysia	227600	8.5	160000	613	4			5	66	37
Penang Port	Sea Port	Malaysia	1260000	12	592400	1620	13		8	32	1	60
North Port Container Terminal (Port Klang)	Sea Port	Malaysia	3597000	15	934000	3026	32	26		84	11	208
West Port Container Terminal (Port Klang)	Sea Port	Malaysia	8393000	17.5	1636000	4900	55			163	27	460
Myanmar Industrial Port	Inland	Myanmar	728000	10	378935	2810	16			14	92	125
Cebu International Terminal	Sea Port	Philippines	285049	9	361200	495	5			14	17	28
General Santos Container Terminal	Sea Port	Philippines	159448	10	30000	588	1				34	8
Manilla International Container Terminal	Sea Port	Philippines	1877000	12.3	330970	1700	13			45	49	96
Subic New Container Terminal 1	Sea Port	Philippines	77619	13	111400	560	4				11	22
Davao Sasa Port	Sea Port	Philippines	135000		95000					3	23	
New Muara Container Terminal	Sea Port	Brunei	106169	12.5	50000	250	2				10	14
Phnom penh Autonomous Port	Inland	Cambodia	133666	8.5	39200	300	3			4	27	20
Sihanoukville Autonomous Port	Sea Port	Cambodia	333904	10.5	65000	400	2			7	9	35
BANGKOK PORT	Inland	Thailand	1536106	8.23	429253	1320.5	22			38	92	162
Hutchison Ports Thailand (1. Thai Laemchabang Terminal Co., Ltd. (TLT) 2. Hutchison Laemchabang Terminal Limited (HLT)	Sea Port	Thailand	2049000	16	623000	1950	16			43	27	76
Songkhla Port	Sea Port	Thailand	151551	9	50000	510					26	15
Saigon Premier Container Terminal	Inland	Vietnam	301382	10.5	60000	500	5			13	5	20
Cai Lan International Container Terminal	Sea Port	Vietnam	49774	10	151000	594	4			12	9	28
Hải Phòng Port	Sea Port	Vietnam	1002987	10.5	404400	3562	47			18	66	96
Đoạn Xá	Inland	Vietnam	214000	8.5	80000	225	4				14	24
Transvina	Inland	Vietnam	79544	7.8	50000	168	2				11	
Định Vũ	Inland	Vietnam	574635	10.2	200000	425	7			4	15	18

PTSC Đình Vũ	Inland	Vietnam	265357	8.5	138269	250	2				18	5
Nam Hải Đình Vũ	Inland	Vietnam	277032	9	120000	300	5				15	60
Quy Nhơn	Sea Port	Vietnam	86766	11.8	50000	565	3			20	15	14
Cai Mep International Terminal	Sea Port	Vietnam	402714	16.5	300000	600	5			15	4	23
Tan Cang-Cai Mep International Terminal	Sea Port	Vietnam	922885	14	34000	590	6			20	1	30
Bình Dương	Inland	Vietnam	78843	6.2	850	100	3				7	10
Tân Cảng Sài Gòn (SAIGON NEW PORT)	Inland	Vietnam	3827115	15.8	2953600	2313	47		8	103	131	485
Bến Nghé port	Inland	Vietnam	148306	13	200000	816	6			6	28	13
VIETNAM INTERNATIONAL CONTAINER TERMINALS (VICT)	Sea Port	Vietnam	583693	11	99840	678	7			10	28	24
Bông Sen (Lotus port)	Inland	Vietnam	84900	9.5	100000		6		3		31	18
Singapore	Sea Port	Singapore	3386900	18	366900	15500	212			488		

Authors' collection

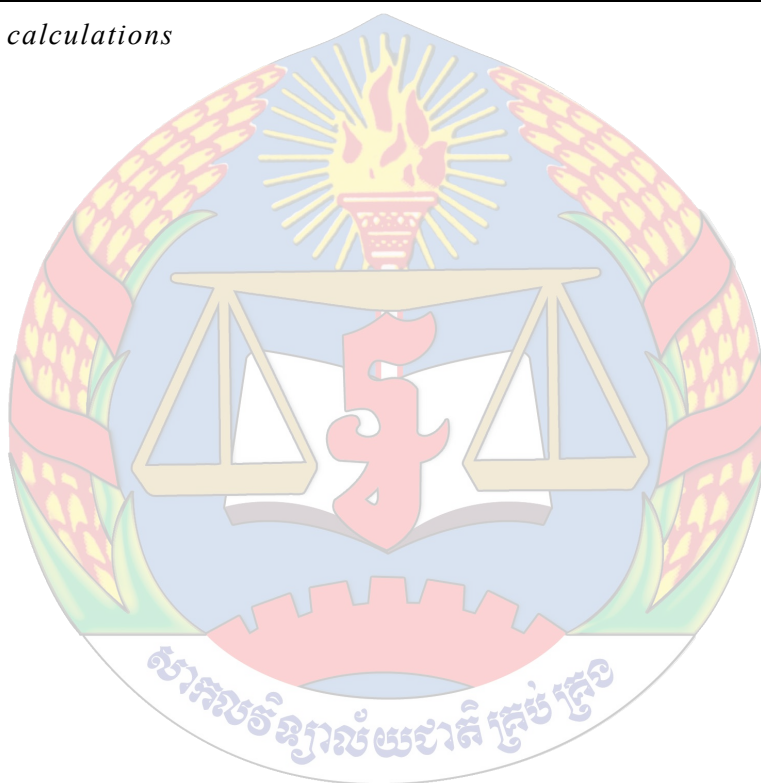


3.B. Category 1 (Inland and Sea Ports with Yard cranes), relative efficiency scores, ranking and returns of scale.

Port	Type	State	TEUs	crste	vrste	scale	Rank Super crste	Super crste	Retu rns
West (Port Klang)	Sea	MYS	8393000	1.00	1.00	1.00	2	0.50	-
Saigon New Port	Inland	VNM	3827115	0.95	0.96	0.99	10	1.05	drs
North (Port Klang)	Sea	MYS	3597000	0.91	0.91	0.99	12	1.10	drs
JICT	Sea	IDN	2373470	1.00	1.00	1.00	7	0.85	-
Hutchison & Thai Laem	Sea	THA	2049000	1.00	1.00	1.00	8	0.89	-
MICT	Sea	PHL	1877000	0.94	0.98	0.96	11	1.06	irs
Bangkok	Inland	THA	1536106	0.73	0.85	0.86	19	1.38	irs
Pet. Surabaya	Sea	IDN	1343523	0.87	0.91	0.96	13	1.15	irs
Penang Port	Sea	MYS	1260000	1.00	1.00	1.00	6	0.66	-
Berlian Jasa	Sea	IDN	1158947	1.00	1.00	1.00	5	0.63	-
Hải Phòng Port	Sea	VNM	1002987	0.75	0.77	0.97	17	1.34	drs
Tan Cang Cai Mep	Sea	VNM	922885	1.00	1.00	1.00	1	0.47	-
BICT	Sea	IDN	900395	0.63	0.63	0.99	23	1.59	drs
KOJA	Sea	IDN	872511	0.82	0.87	0.94	15	1.22	irs
Myanmar Ind. Port	Inland	MMR	728000	0.67	0.68	1.00	21	1.49	irs
Tanjung Perak	Sea	IDN	601915	1.00	1.00	1.00	3	0.58	-
VICT	Sea	VNM	583693	0.85	0.85	1.00	14	1.17	irs
Pet. Semarang	Sea	IDN	575671	0.74	0.93	0.79	18	1.36	irs
Đình Vũ	Inland	VNM	574635	1.00	1.00	1.00	4	0.60	-
Makassar	Sea	IDN	562046	0.78	0.84	0.93	16	1.28	irs
Banjarmasin	Sea	IDN	413737	0.65	1.00	0.65	22	1.54	irs
Cai Mep IC	Sea	VNM	402714	0.57	0.66	0.86	24	1.77	irs
PAS	Sea	KHM	333904	1.00	1.00	1.00	9	0.95	-
Saigon Premier	Inland	VNM	301382	0.48	0.71	0.68	27	2.09	irs
Cebu	Sea	PHL	285049	0.40	0.52	0.77	30	2.50	irs
Kuching Port	Inland	MYS	227600	0.56	0.67	0.83	25	1.79	irs
Pontianak	Inland	IDN	227130	0.70	1.00	0.70	20	1.44	irs
Bitung	Sea	IDN	200153	0.55	1.00	0.55	26	1.82	irs

Bến Nghé port	Inland	VNM	148306	0.33	0.42	0.79	32	3.02	irs
Palembang	Inland	IDN	137685	0.35	1.00	0.35	31	2.85	irs
PPAP	Inland	KHM	133666	0.48	1.00	0.48	28	2.10	irs
Kuantan Port	Sea	MYS	131000	0.43	1.00	0.43	29	2.35	irs
Panjang Port	Sea	IDN	107546	0.24	0.28	0.84	33	4.22	irs
Quy Nhơn	Sea	VNM	86766	0.20	1.00	0.20	35	5.00	irs
Bông Sen (Lotus port)	Inland	VNM	84900	0.23	1.00	0.23	34	4.32	irs
Cai Lan ICT	Sea	VNM	49774	0.08	0.11	0.79	37	12.08	irs
Jambi Port	Inland	IDN	29379	0.14	1.00	0.14	36	7.23	irs
mean				0.68	0.85	0.80			

Source: Authors' calculations



3.C. Category 2 (Inland and Sea Ports with RTGC and Forklift), relative efficiency scores, ranking and returns of scale.

Port	Type	Country	TEUs	crste	vrste	scale	RANK SUPER CRS	SUPER CRS	
West (Port Klang)	Sea	MYS	8393000	1.00	1.00	1.00	1.00	0.29	-
JICT	Sea	IDN	2373470	1.00	1.00	1.00	6.00	0.85	-
Hutchison & Thai Laem	Sea	THA	2049000	1.00	1.00	1.00	7.00	0.89	-
MICT	Sea	PHL	1877000	0.94	1.00	0.94	9.00	1.06	irs
BANGKOK PORT	Inland	THA	1536106	0.73	1.00	0.73	16.00	1.38	irs
Pet. Surabaya	Sea	IDN	1343523	0.87	0.95	0.92	10.00	1.15	irs
Berlian Jasa	Sea	IDN	1158947	1.00	1.00	1.00	5.00	0.63	-
Hải Phòng Port	Sea	VNM	1002987	0.75	0.77	0.97	14.00	1.34	drs
Tan Cang Cai Mep	Sea	VNM	922885	1.00	1.00	1.00	2.00	0.47	-
BICT	Sea	IDN	900395	0.63	0.63	0.99	19.00	1.59	drs
KOJA Terminal	Sea	IDN	872511	0.82	0.87	0.94	12.00	1.22	irs
Myanmar Industrial Port	Inland	MMR	728000	0.67	0.68	1.00	17.00	1.49	irs
Tanjung Perak	Sea	IDN	601915	1.00	1.00	1.00	3.00	0.58	-
VICT	Sea	VNM	583693	0.85	0.85	1.00	11.00	1.17	irs
Pet. Semarang	Sea	IDN	575671	0.74	0.97	0.76	15.00	1.36	irs
Đình Vũ	Inland	VNM	574635	1.00	1.00	1.00	4.00	0.60	-
Makassar	Sea	IDN	562046	0.78	0.93	0.84	13.00	1.28	irs
Banjarmasin	Sea	IDN	413737	0.65	1.00	0.65	18.00	1.54	irs
Cai Mep IC	Sea	VNM	402714	0.57	0.67	0.85	20.00	1.77	irs
PAS	Sea	KHM	333904	1.00	1.00	1.00	8.00	0.95	-
Saigon Premier	Inland	VNM	301382	0.48	0.76	0.63	22.00	2.09	irs
Cebu	Sea	PHL	285049	0.40	0.69	0.58	25.00	2.50	irs
Kuching Port	Inland	MYS	227600	0.56	0.99	0.57	21.00	1.79	irs
Bến Nghé port	Inland	VNM	148306	0.33	0.42	0.78	26.00	3.02	irs
PPAP	Inland	KHM	133666	0.48	1.00	0.48	23.00	2.10	irs
Kuantan Port	Sea	MYS	131000	0.43	1.00	0.43	24.00	2.35	irs
Panjang Port	Sea	IDN	107546	0.24	1.00	0.24	27.00	4.22	irs
Quy Nhơn	Sea	VNM	86766	0.20	1.00	0.20	28.00	5.00	irs
Cai Lan ICT	Sea	VNM	49774	0.08	0.12	0.67	29.00	12.08	irs
mean				0.70	0.87	0.80			

Source: Authors' calculations

3.D. Category 3 (Sea Ports with Yard Cranes), relative efficiency scores, ranking and returns of scale.

Port	State	TEUs	crste	vrste	scale	Rank Super CRS	SUPER CRS	Return s
West Port (Port Klang)	MYS	8393000	1.00	1.00	1.00	2	0.50	-
North Port (Port Klang)	MYS	3597000	0.91	0.91	0.99	11	1.10	drs
JICT	IDN	2373470	1.00	1.00	1.00	6	0.85	-
Hutchison & Thai Laem.	THA	2049000	1.00	1.00	1.00	7	0.89	-
MICT	PHL	1877000	0.93	0.93	1.00	9	1.06	-
Pet. Surabaya	IDN	1343523	0.90	0.95	0.95	12	1.12	irs
Penang Port	MYS	1260000	1.00	1.00	1.00	5	0.66	-
Berlian Jasa	IDN	1158947	1.00	1.00	1.00	4	0.63	-
Hải Phòng Port	VNM	1002987	0.75	0.77	0.97	15	1.34	drs
Tan Cang Cai Mep	VNM	922885	1.00	1.00	1.00	1	0.47	-
BICT	IDN	900395	0.63	0.63	1.00	18	1.59	drs
KOJA	IDN	872511	0.82	0.87	0.94	14	1.22	irs
Tanjung Perak	IDN	601915	1.00	1.00	1.00	3	0.58	-
VICT	VNM	583693	0.91	0.93	0.98	10	1.09	irs
Pet. Semarang	IDN	575671	0.74	0.99	0.74	16	1.36	irs
Makassar	IDN	562046	0.82	0.95	0.86	13	1.22	irs
Banjarmasin	IDN	413737	0.66	1.00	0.66	17	1.52	irs
Cai Mep IT	VNM	402714	0.57	0.66	0.86	19	1.77	irs
PAS	KHM	333904	1.00	1.00	1.00	8	0.95	-
Cebu	PHL	285049	0.41	1.00	0.41	22	2.45	irs
Bitung	IDN	200153	0.55	1.00	0.55	20	1.82	irs
Kuantan Port	MYS	131000	0.43	1.00	0.43	21	2.35	irs
Panjang Port	IDN	107546	0.25	1.00	0.25	23	4.00	irs
Quy Nhơn	VNM	86766	0.20	1.00	0.20	24	5.00	irs
Cai Lan ICT	VNM	49774	0.08	0.13	0.66	25	12.03	irs
Mean			0.741	0.908	0.818			

Source: Authors' calculations

3.E. Category 4 (Sea Ports with RTGC and Forklift), relative efficiency scores, ranking and returns of scale.

Port	State	TEUs	crste	vrste	scale	Super crste	Rank Super crste	Returns
West Terminal (Port Klang)	MYS	8393000	1.00	1.00	1.00	0.29	1	-
Tan Cang-Cai Mep IT	VNM	922885	1.00	1.00	1.00	0.47	2	-
Tanjung Perak Port	IDN	601915	1.00	1.00	1.00	0.58	3	-
Berlian Jasa Terminal	IDN	1158947	1.00	1.00	1.00	0.63	4	-
JICT	IDN	2373470	1.00	1.00	1.00	0.85	5	-
PAS	KHM	333904	1.00	1.00	1.00	0.95	6	-
MICT	PHL	1877000	0.92	0.98	0.94	1.09	7	irs
Thai Laemchabang Terminal Co. & Hutchison Laemchabang Terminal Limited	THA	2049000	0.90	0.91	1.00	1.11	8	irs
VICT	VNM	583693	0.90	0.91	0.99	1.11	9	irs
Petikemas Surabaya	IDN	1343523	0.90	0.94	0.95	1.12	10	irs
Makassar	IDN	562046	0.82	0.95	0.86	1.22	11	irs
KOJA Terminal	IDN	872511	0.81	0.87	0.93	1.23	12	irs
Hải Phòng Port	VNM	1002987	0.75	0.77	0.97	1.34	13	drs
Petikemas Semarang	IDN	575671	0.74	0.99	0.74	1.36	14	irs
Banjarmasin	IDN	413737	0.66	1.00	0.66	1.52	15	irs
BICT	IDN	900395	0.62	0.62	1.00	1.61	16	irs
Cai Mep IT	VNM	402714	0.52	0.56	0.94	1.91	17	irs
Cebu International Terminal	PHL	285049	0.39	1.00	0.39	2.56	18	irs
Kuantan Port	MYS	131000	0.34	1.00	0.34	2.91	19	irs
Panjang Port	IDN	107546	0.25	1.00	0.25	4.00	20	irs
Quy Nhơn	VNM	86766	0.18	1.00	0.18	5.62	21	irs
Cai Lan ICT	VNM	49774	0.08	0.11	0.75	12.34	22	irs
Mean			0.72	0.89	0.81			

Source: Authors' calculations

3.F. Category 5 (Inland ports), relative efficiency scores, ranking and returns of scale.

Port	State	TEUs	crste	vrste	scale	Rank Super crste	Super crste	Returns
Bình Dương	VNM	78843	1.00	1.00	1.00	1	0.05	-
BANGKOK PORT	THY	1536106	1.00	1.00	1.00	2	0.50	-
PTSC Đình Vũ	VNM	265357	1.00	1.00	1.00	3	0.62	-
Tân Cảng Sài Gòn (SAIGON NEW PORT)	VNM	3827115	1.00	1.00	1.00	4	0.71	-
Đình Vũ	VNM	574635	1.00	1.00	1.00	5	0.90	-
Saigon Premier Container Terminal	VNM	301382	1.00	1.00	1.00	6	0.94	-
Pontianak	IDN	227130	1.00	1.00	1.00	7	0.98	-
Đoạn Xá	VNM	214000	0.79	0.85	0.93	8	1.27	irs
Nam Hải Đình Vũ	VNM	277032	0.73	0.76	0.96	9	1.37	irs
Phnom penh Autonomous Port	KHM	133666	0.72	0.90	0.80	10	1.38	irs
Myanmar Industrial Port	MMR	728000	0.61	0.62	0.98	11	1.63	drs
Kuching Port	MYS	227600	0.59	0.59	1.00	12	1.69	irs
Palembang	IDN	137685	0.50	0.51	0.98	13	2.00	drs
Bến Nghé port	VNM	148306	0.28	0.29	0.99	14	3.56	drs
Bông Sen (Lotus port)	VNM	84900	0.22	0.22	0.99	15	4.61	irs
Jambi Port	IDN	29379	0.20	0.23	0.91	16	4.91	drs
Mean			0.728	0.748	0.971			

Source: Authors' calculations

3.G. Category 6 (Inland Ports with Yard cranes), relative efficiency scores, ranking and returns of scale.

Port	Inputs (2) Depth; CY size			Inputs (2) Depth; and length			Inputs (2) depth; quay cranes			Inputs (2) CY size; length			Inputs (2) CY size; forklifts			Inputs (2) length; Yard Cranes			Input (2) Length; Forklifts			Inputs (2) length; trucks		
	crst e	vrst e	scal e	crst e	vrst e	scal e	crst e	vrst e	scal e	crst e	vrst e	scal e	crst e	vrst e	scal e	crst e	vrst e	scal e	crst e	vrst e	scal e	crst e	vrst e	scal e
Palemban g	0.49	0.49	1.00	0.31	1.00	0.31	0.24	0.25	0.94	0.58	1.00	0.58	0.48	0.48	0.99	0.37	1.00	0.37	0.31	1.00	0.31	0.38	1.00	0.38
Pontianak	1.00	1.00	1.00	0.47	1.00	0.47	0.69	1.00	0.69	1.00	1.00	1.00	0.95	1.00	0.95	0.56	1.00	0.56	0.47	1.00	0.47	0.56	1.00	0.56
Jambi Port	0.40	1.00	0.40	0.06	0.12	0.49	0.09	0.12	0.74	0.40	1.00	0.40	0.40	1.00	0.40	0.07	1.00	0.07	0.07	1.00	0.07	0.15	1.00	0.15
Kuching Port	0.36	0.36	0.99	0.22	0.28	0.81	0.69	0.94	0.74	0.37	0.37	1.00	0.28	0.36	0.79	0.32	0.38	0.84	0.22	0.25	0.89	0.27	0.32	0.83
Myanmar Port	0.53	0.53	0.99	0.30	0.35	0.86	0.56	0.58	0.97	0.39	0.53	0.74	0.38	0.53	0.72	0.36	0.83	0.44	0.20	0.27	0.76	0.19	0.55	0.35
PPAP	0.68	0.76	0.90	0.27	0.56	0.48	0.54	1.00	0.54	0.69	0.76	0.91	0.68	0.76	0.90	0.32	0.56	0.58	0.27	0.56	0.48	0.32	0.56	0.57
Bangkok Port	1.00	1.00	1.00	0.77	1.00	0.77	0.86	1.00	0.86	1.00	1.00	1.00	0.71	1.00	0.71	0.77	0.96	0.81	0.70	0.73	0.97	0.78	0.97	0.80
Saigon Premier	1.00	1.00	1.00	0.36	0.43	0.85	0.73	0.85	0.86	1.00	1.00	1.00	1.00	1.00	1.00	0.41	0.43	0.95	1.00	1.00	1.00	0.47	0.51	0.92
Đinh Vũ	0.73	0.75	0.98	0.82	1.00	0.82	1.00	1.00	1.00	1.00	1.00	1.00	0.64	1.00	0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Saigon New Port	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.49	1.00	0.49	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bến Nghé port	0.18	0.19	0.94	0.11	0.12	0.92	0.30	0.32	0.94	0.19	0.19	0.97	0.15	0.22	0.68	0.17	0.23	0.74	0.14	0.16	0.88	0.36	0.43	0.84
Bông Sen (Lotus port)	0.19	0.20	0.97	0.13	0.16	0.78	0.17	0.18	0.94	0.22	0.22	0.98	0.17	0.20	0.87	0.20	1.00	0.20	0.13	0.16	0.78	0.16	0.16	0.95
mean	0.63	0.69	0.93	0.40	0.58	0.71	0.57	0.69	0.85	0.65	0.76	0.88	0.53	0.71	0.76	0.46	0.78	0.63	0.46	0.68	0.72	0.47	0.71	0.70

Source: Authors' calculations

Note: 8 DEA-Output oriented models with 2 inputs and 1 output were created

3.H. Explained variance by component in the PCA analysis (Category 1)

Axis	Variance of the axis (eigenvalue)	% of explained variance	Cumulated % of explained variance	Retained according to Kaiser's criterion
1	3.524	50.3	50.3	X
2	1.225	17.5	67.8	X
3	0.926	13.2	81.1	
4	0.504	7.2	88.3	
5	0.438	6.3	94.5	
6	0.207	3.0	97.5	
7	0.177	2.5	100.0	
Total	7.000	100.0	100.0	

Source: Authors' calculations

3.I. Correlation coefficients of active variables with the axis and the contribution of the active variables to the axis

	Correlations between active variables and factors		Contributions of the active variables to the axes (in %)	
	Axis 1	Axis 2	Axis 1	Axis 2
TEU/depth	0.58	0.68	9.51	38.26
TEU/Size_CY	0.63	-0.51	11.21	20.83
TEU/Length_quays	0.89	0.24	22.31	4.55
TEU/Cranes_quay	0.74	0.42	15.65	14.64
TEU/Cranes_CY	0.61	-0.35	10.67	10.16
TEU/Forklifts	0.60	-0.17	10.38	2.35
TEU/Trucks	0.85	-0.34	20.27	9.20

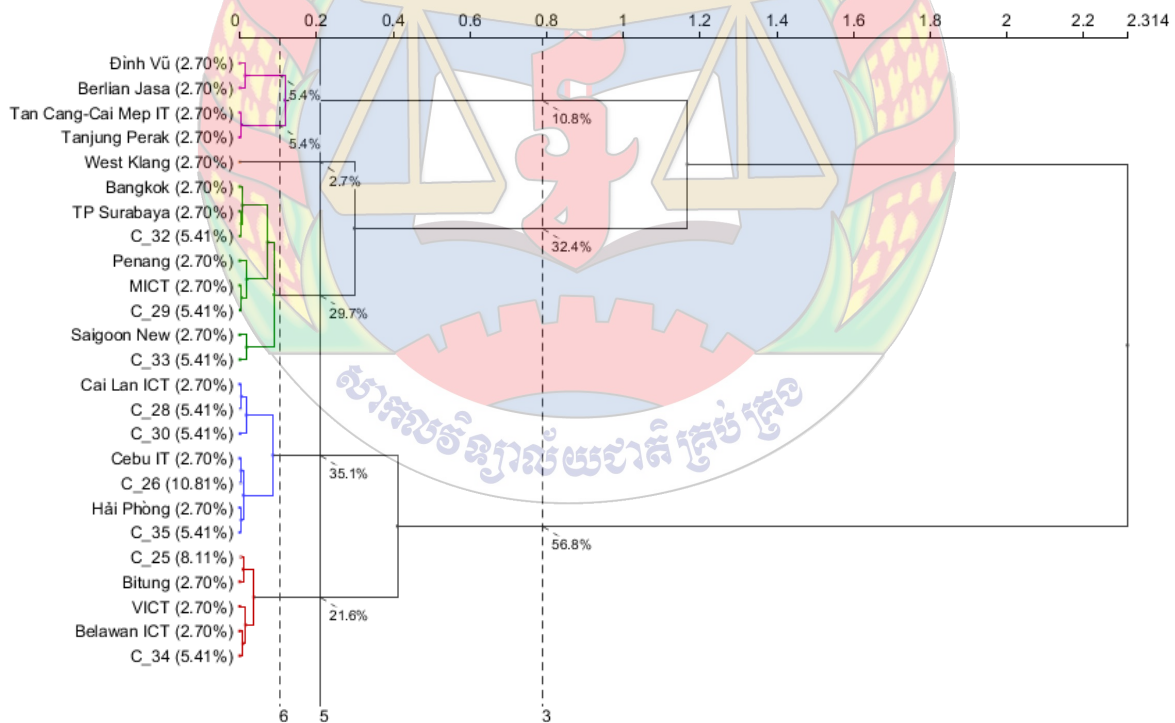
Source: Authors' calculations

3.J. Indicators of the quality of the identified clusters following Agglomerative Hierarchical Clustering

Criteria	3 clusters	4 clusters	5 clusters	6 clusters	7 clusters	8 clusters
Intra-cluster inertia	1.27	0.86	0.56	0.44	0.35	0.27
Inter-cluster inertia	3.48	3.89	4.19	4.31	4.40	4.48
Explained inertia (%)	73.29	81.95	88.24	90.71	92.60	94.42
Calinski-Harabasz (pseudo F) criterion	46.65	49.93	60.03	60.57	62.55	70.10
Davies-Bouldin's index	0.63	0.66	0.56	0.52	0.59	0.60

Source: Authors' calculations

3.K. Dendrogram, Agglomerative Hierarchical Clustering based on the Ward criterion for the sample of 34.

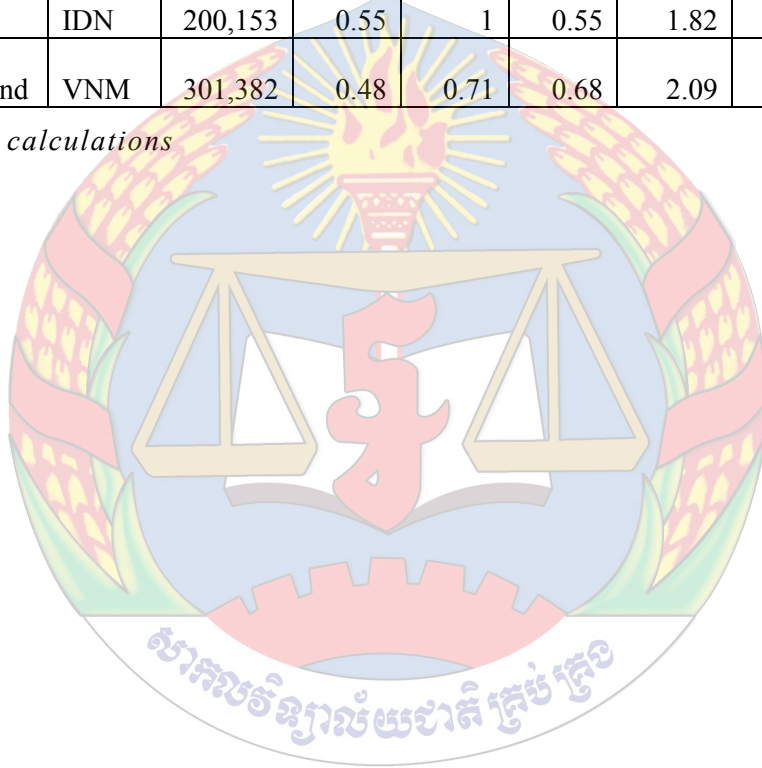


Source: Authors' calculations and visualization

3.L. DEA results of ports belonging to Cluster 1

Port	Type	State	TEUs	crste	vrste	scale	Super crste	Rank Super crste	Returns
VICT	Sea	VNM	583,693	0.85	0.85	1	1.17	14	irs
Makassar	Sea	IDN	562,046	0.78	0.84	0.93	1.28	16	irs
Pontianak	Inland	IDN	227,130	0.7	1	0.7	1.44	20	irs
Banjarmasin	Sea	IDN	413,737	0.65	1	0.65	1.54	22	irs
BICT	Sea	IDN	900,395	0.63	0.63	0.99	1.59	23	drs
Cai Mep IC	Sea	VNM	402,714	0.57	0.66	0.86	1.77	24	irs
Bitung	Sea	IDN	200,153	0.55	1	0.55	1.82	26	irs
Saigon Premier	Inland	VNM	301,382	0.48	0.71	0.68	2.09	27	irs

Source: Authors' calculations



3.M. DEA results of ports belonging to Cluster 2

Port	Type	State	TEUs	crste	vrste	scale	Super crste	Rank Super crste	Retur ns
Hải Phòng Port	Sea	VNM	1,002,987	0.75	0.77	0.97	1.34	17	drs
Myanmar Ind. Port	Inland	MMR	728,000	0.67	0.68	1	1.49	21	irs
Kuching Port	Inland	MYS	227,600	0.56	0.67	0.83	1.79	25	irs
PPAP	Inland	KHM	133,666	0.48	1	0.48	2.1	28	irs
Kuantan Port	Sea	MYS	131,000	0.43	1	0.43	2.35	29	irs
Cebu	Sea	PHL	285,049	0.4	0.52	0.77	2.5	30	irs
Palembang	Inland	IDN	137,685	0.35	1	0.35	2.85	31	irs
Bến Nghé port	Inland	VNM	148,306	0.33	0.42	0.79	3.02	32	irs
Panjang Port	Sea	IDN	107,546	0.24	0.28	0.84	4.22	33	irs
Bông Sen (Lotus port)	Inland	VNM	84,900	0.23	1	0.23	4.32	34	irs
Quy Nhơn	Sea	VNM	86,766	0.2	1	0.2	5	35	irs
Jambi Port	Inland	IDN	29,379	0.14	1	0.14	7.23	36	irs
Cai Lan ICT	Sea	VNM	49,774	0.08	0.11	0.79	12.08	37	irs

Source: Authors' calculations

3.N. DEA results of ports belonging to Cluster 3

Port	Type	State	TEUs	crste	vrste	scale	Super crste	Rank Super crste	Returns
Hutchison & Thai Laem	Sea	THA	2,049,000	1	1	1	0.89	8	-
JICT	Sea	IDN	2,373,470	1	1	1	0.85	7	-
PAS	Sea	KHM	333,904	1	1	1	0.95	9	-
Penang Port	Sea	MYS	1,260,000	1	1	1	0.66	6	-
Saigon New Port	Inland	VNM	3,827,115	0.95	0.96	0.99	1.05	10	drs
MICT	Sea	PHL	1,877,000	0.94	0.98	0.96	1.06	11	irs
North (Port Klang)	Sea	MYS	3,597,000	0.91	0.91	0.99	1.1	12	drs
Pet. Surabaya	Sea	IDN	1,343,523	0.87	0.91	0.96	1.15	13	irs
KOJA	Sea	IDN	872,511	0.82	0.87	0.94	1.22	15	irs
Pet. Semarang	Sea	IDN	575,671	0.74	0.93	0.79	1.36	18	irs
Bangkok	Inland	THA	1,536,106	0.73	0.85	0.86	1.38	19	irs

Source: Authors' calculations

3.O. DEA results of ports belonging to Cluster 4

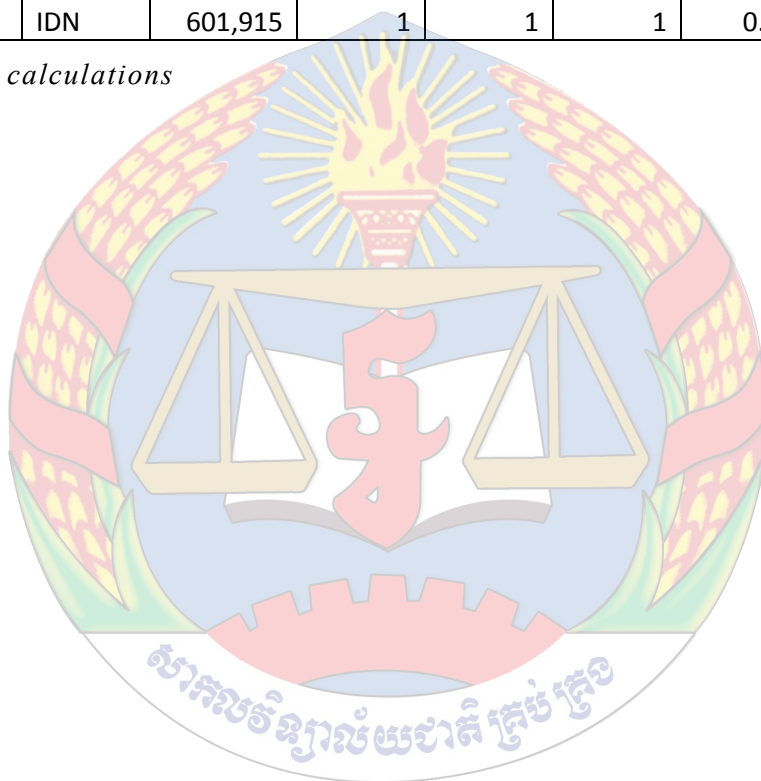
Port	Type	State	TEUs	crste	vrste	scale	Super crste	Rank Super crste	Returns
West (Port Klang)	Sea	MYS	8,393,000	1	1	1	0.5	2	-

Source: Authors' calculations

3.P. DEA results of ports belonging to Cluster 5

Port	Type	State	TEUs	crste	vrste	scale	Super crste	Rank Super crste	Returns
Berlian Jasa	Sea	IDN	1,158,947	1	1	1	0.63	5	-
Đình Vũ	Inland	VNM	574,635	1	1	1	0.6	4	-
Tan Cang Cai Mep	Sea	VNM	922,885	1	1	1	0.47	1	-
Tanjung Perak	Sea	IDN	601,915	1	1	1	0.58	3	-

Source: Authors' calculations



Chapter 4. Assessing competition on Maritime Routes in the Liner Shipping Industry through multivariate analysis



Assessing competition on Maritime Routes in the Container Liner Shipping Industry through multivariate analysis

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Abstract

The current paper investigates the level of competition on maritime routes in the liner shipping industry by applying multivariate and cluster analyses of maritime indicators. We use a dataset which includes maritime routes between 153 ports for the year 2014, described by several characteristics regarding the number of operators, the number of ships and trips, the size of ships, the sea distance, the bilateral countries' connectivity. Some clusters of maritime routes are identified along two key components, the first one related to the number of competing container carriers, positively correlated with the number of ships and trips on the maritime routes, and the second one where the average size number of ships per carrier is related to the sea distance and the size of the vessels. The first component indicates the degree of competition while the second one is related to the efficiency of carriers. Another way of looking at competition is to consider the region-based trade and to see whether indicators respond differently from region to region.

Keywords: multivariate analysis, clusters, competition, shipping.

4.1. Introduction

Since the invention of the shipping container by Malcolm McLean in 1956, the containerized trade has experienced a remarkable growth. It allowed port operators and shipping carriers to reduce their loading and unloading costs and to considerably improve their time efficiency. According to Clarkson Research's data, since 1990 the container trade has increased by more than 600%. In 2016, it accounted for only 16.7% of the total seaborne trade, while its value was more than 60%⁶⁹. In the last decades, we have observed a specialization of the ports by investing in the construction and enlargement of container terminals and connections with the hinterland network. Major investments, such as the \$8.2 billion expansion program of the Suez Canal completed in July 2015⁷⁰ and the enlargement of the Panama Canal for \$5.25 billion achieved in June 2016, made the operation of large container vessels faster and cheaper.

From 1999 to 2016, the average size of containerships and the volume of containerized cargo per mile have increased by 127% and 208%⁷¹, respectively. This positive trend is largely driven by the rapid pace of globalization which was amplified by the inclusion of China in the WTO membership in December 2001. As a consequence of globalization, the prevailing network structure in the maritime trade has turned into a "hub and spoke" structure. Some ports, such as Hong Kong and Singapore, located on central strategic geographical sites (hubs), have direct connections with regional ports (feeders or spokes) and other hub ports.

Along this hub and spoke network organization, the liner shipping industry has been rapidly developed by exploiting large increasing returns to scale, through which the most transited routes are covered by the largest ships, having a high loading factor and organized within alliances (Yang et al., 2016). Such a growing average size of ships on a few major routes linking port hubs has reduced the number of liner companies after several waves of mergers & acquisitions (Clark et al., 2004). For market leaders, such an external growth strategy represents a way of defending their positions and increasing entry barriers, like the recent Maersk Line's acquisition of Hamburg Süd and the takeover of Neptune Orient Lines by CMA-CGM in 2017. Furthermore, the excessive

⁶⁹ <http://www.worldshipping.org/about-the-industry/global-trade>

⁷⁰ <https://www.economist.com/news/middle-east-and-africa/21660555-it-necessary-bigger-better-suez-canal>

⁷¹ Data from Clarkson Research

capacity in the industry has led to further market consolidation through consortia and alliances (Agarwal and Ergun, 2010, Panayides and Wiedmer, 2011),. In 2018, three Mega Shipping Alliances include the ten biggest container lines in the world, collectively accounting for 79% of the global container market⁷². Secondary maritime routes with lower trade volumes are covered by smaller companies operating smaller vessels (Clark et al., 2004). Despite the process of concentration and alliances, container freight rates remain at very low levels, and competition on various trade routes has even intensified (UNCTAD, 2017). One of the reasons lies in the imbalance between supply and demand, which has raised shippers' bargaining power benefiting from the upsizing race among shipping companies.

The objective of this research is to analyze the competition on the maritime routes by addressing the following research questions. What is the degree of competition on the different maritime routes? How do the sea distance, bilateral countries connectivity as well as regional trade direction influence the level of competition between liner shipping carriers? How can the different maritime routes be classified in terms of competition, and to what extent the geographical location of ports matters in this typology of routes? To answer these questions, multivariate and cluster analyses have been used on a sample of 153 container ports in 50 countries.

The paper is structured as follows. Firstly, a review of literature on competition between container carriers is provided. Secondly, the methodology related to multivariate analysis along with information about the dataset and the used variables are depicted. Thirdly, the results as well as a discussion of the outcomes of this research are shown. Finally, the conclusion of the main findings and some proposals for further research are developed.

⁷² <https://www.xeneta.com/blog/shipping-alliances>

4.2. Literature Review

Competition can have different theoretical meanings: more freedom for firms (free entry or exit in the market), an increasing number of rivals, a move away from collusion towards more independent behaviors, or the reward to obtain, or the penalty, etc. (Vickers, 1995). When applied to transportation, competition is narrowly combined with cooperation – forming by contraction the concept of “coopetition” Dagnino and Rocco (2009) to cope with the network constraints and the interdependence of maritime routes as sub-markets. By many aspects, the market conditions of shipping services look like those observed in the airline industry, where the theoretical conditions for perfect contestability are far from being satisfied (Hurdle et al., 1989, Notteboom, 2002), no sunk cost of entry for entrants, same post-entry costs for incumbent and entrants, etc. However, competition is stiff enough to keep freight rates at low levels in spite of the ongoing M&A and concentration process.

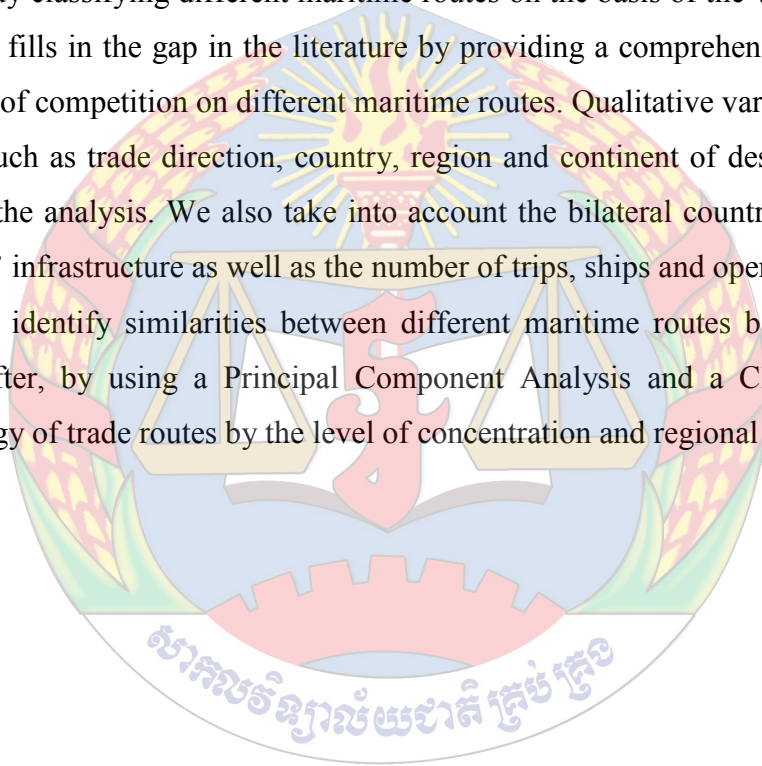
Due to this competitive regime, ocean container carriers have continuously sought to maximize their market share and/or minimize their running costs (Song, 2002). Clark et al. (2004) demonstrate that directional imbalance in trade between countries implies that many carriers have to haul empty containers back. It has a positive effect on the cost of shipments, leading shipping companies to coalesce within conferences or capacity-sharing agreements. The study also shows that maritime conferences have been exerting some mild monopoly power, adding around 5% to transport costs. However, other studies have found that conference outsiders have increased their market share on a few major routes and that a great proportion of service contracts did not even use the official tariffs of shipping conferences, even though companies were members (Cariou, 2008, Cariou and Wolff, 2006). This would explain the repeal of the shipping conference exemption by the European Union in the late 2000s (Global Insight, 2005).

The cooperation between the top 20 ocean shipping companies was analyzed by Panayides and Wiedmer (2011). Their results show that focal members of an alliance maintain preferred relationships for service agreements that are adjusted on a continuous basis. The “global alliances” can hardly be seen as closed “entities”. Ha and Seo (2017) used a panel data model to determine to what extent freight rates, bunker fuel prices, scale economies and chartered vessel ratios had affected the profits of major shipping carriers. It was found that the route specialization did not

necessary influence the companies' profit. Hirata (2017) applied a similar approach to estimate the effect of the Hirschmann-Herfindahl Index (HHI) on container freight rates for a sample of six major container liner shipping routes. Results suggest that higher concentration level does not lead to higher prices, and that the container liner shipping market is rather contestable. Therefore, alliances do not hamper competition, but would rather present solutions how to lower unit operating costs. Concentration might nonetheless have a more significant impact on freight rates on secondary markets such as the south-American routes, even though increasing rates can also be explained by demand factors (Sanchez and Wilmsmeier, 2011). This is confirmed by other studies reporting that peripheral markets are more subject to the influence of concentration than main ones: only large carriers can enter and challenge the market positions of incumbents which manage to create entry barriers for smaller outsiders. Sys (2009) analyzed the degree of concentration by estimating the following coefficients: the HHI, the Lorenz curve and the Gini coefficient as well as the Hymer–Pashigan index of market share instability. This study shows first how the global shipping market concentrated tremendously within a decade (2000-2009), the cumulated share of the top-10 companies passing from 38 to 60%, and the Gini coefficient, yet very high, gaining 10 points, from 0.66 to 0.77. Secondly, two groups of maritime routes were identified. The first one was characterized as a loose oligopolistic market which includes large trade lanes (e.g. transatlantic and transpacific trade for a total trade of 41,000,000 TEU), while the second one is a tight oligopoly which includes new/growing/relatively small container trade routes (e.g. Mediterranean—North America, 1,000,000 TEU volume).

A container industry-specific real options investment model of oligopolistic competition, taking into account endogenous price formation in the second-hand vessel market, fuel-efficient investment and endogenous lead times, was developed by Rau and Spinler (2016). The outcomes of the study demonstrate that an increasing number of players (moving from monopoly to oligopoly) results in higher optimal capacities, lower individual firm values as well as earlier investment. However, an increase in competitive intensity was deemed to reduce optimal capacity and firm value. Wang et al. (2014) conclude that the expansion of the fleet capacity is less costly than updating the frequency of the required services. An additional incentive for cooperation might be the fact that the “grand coalition’s” profit is always higher than the sum of “subcoalition” ones (Liu et al., 2016).

In the literature, many variables have been used to analyze the nature and the degree of competition in the container trade. The geographical locations (Anderson et al., 2008, Clark et al., 2004, De Oliveira and Cariou, 2015, Fraser et al., 2016, Yap et al., 2006), the connectivity of the country and the physical infrastructure (Yeo et al., 2008, Fraser et al., 2016) should be considered. Directional imbalance of the trade was taken into account in the studies of Asgari et al. (2013) and Clark et al. (2004). The increasing size of the fleet and incentives for economies of scale were analyzed in Notteboom and Yap (2012), Ha and Seo (2017) and Rau and Spinler (2016). The oligopolistic nature of the liner shipping industry was shown by Sys (2009). However, we have not found any study classifying different maritime routes on the basis of the variables mentioned above. This paper fills in the gap in the literature by providing a comprehensive analysis of the nature and degree of competition on different maritime routes. Qualitative variables related to the maritime routes such as trade direction, country, region and continent of destination and origin were included in the analysis. We also take into account the bilateral country connectivity as a proxy of the ports' infrastructure as well as the number of trips, ships and operators between each pair of ports. We identify similarities between different maritime routes based on this set of variables. Thereafter, by using a Principal Component Analysis and a Cluster Analysis we highlight a typology of trade routes by the level of concentration and regional characteristics.



4.3. Methodology

4.3.1. Data

In this paper we have used data from multiple sources. A dataset on the ports' connectivity was obtained from Lloyd's List Intelligence⁷³. It contains port to port connectivity in 2014 for 153 ports from 50 countries.

Table 4.1: Distribution of ports and countries in the sample according to the continents

	Countries	Ports
Americas	11	35
Europe	12	20
Asia	18	79
Africa	9	19
Total	50	153

Source: Lloyd's List Intelligence

As shown in Table 4.1, most of the ports are located in Asia, followed by Central, Latin and North America, Europe, and Africa. The dataset contains information about 6,410 maritime routes. For each route, we have the following descriptive variables:

- port of departure and port of arrival,
- country, region and continent of departure and arrival,

In addition to these categorical variables, we have the following continuous and discrete variables for each maritime route:

⁷³ <https://www.lloydslistintelligence.com/>

- Average size of container vessels measured in twenty-feet equivalent units (TEU) operating between a port of departure and a port of arrival;
- Number of ships between a port of departure and a port of arrival;
- Number of trips between a port of departure and a port of arrival;
- Number of operators (liner shipping container carriers) operating between a port of departure and a port of arrival;
- Number of ships per operator on a maritime route.

We have also included in our analysis the bilateral sea-distance between the main container ports in each country. It was computed by Bertoli et al. (2016). The database is developed at the country level and, if the two ports belong to the same country, the distance is set at zero. This variable shows the relative length of each maritime route.

Another variable at a country level which we use for the analysis is the Liner Shipping Bilateral Connectivity Index (LSBCI), which was developed by Hoffmann et al. (2014). LSBCI is an extension of UNCTAD's country level Liner Shipping Connectivity Index (LSCI). The LSBCI includes the following components: 1) the number of transshipments required to get from country A to country B; 2) the number of direct connections common to both country A and country B; 3) the geometric mean of the number of direct connections of country A and of country B; 4) the level of competition on services that connect country A to country B; 5), the size of the largest ships on the weakest route connecting country A to country B (Fugazza and Hoffmann, 2016).

Finally, the descriptive variable Trade Direction is a descriptive variable and allows analyzing the imbalance of container trade between developed and less developed countries. We use the analytical classification made by the World Bank of the world's economies based on estimates of gross national income (GNI) per capita for 2014⁷⁴. Countries classified as High Income states are considered as Developed (D), while the remaining countries are considered "Less Developed" (DL). We obtain therefore four types of trade directions, D-D, LD-LD, D-LD and LD-D.

⁷⁴ <https://blogs.worldbank.org/opendata/new-country-classifications-2016>

Table 4.2 Variables used in this study

Variable Name	Description	Source
Avg_TEU	Average size of container vessels operating on a given maritime route, measured in TEU	Lloyd's List Intelligence
Ships	Number of ships between a port of departure and a port of arrival;	Lloyd's List Intelligence
Trips	Number of trips between a port of departure and a port of arrival	Lloyd's List Intelligence
Carriers	Number of liner shipping container carriers operating between a port of departure and a port of arrival	Lloyd's List Intelligence
Ships_per_carrier	Number of ships per operator on a maritime route	Computed by authors
Distance	Bilateral sea-distance between the main container ports in each country, measured in nautical miles	Bertoli et al. (2016)
LSBCI	Liner Shipping Bilateral Connectivity Index	Hoffmann et al. (2014)
Trade_direction	Direction of trade according to the national income of the country of departure and the country of arrival.	World Bank

Source: Authors' collections

Table 4.2 provides a summary of the variables that we have used in this study. All data are secondary data collected from various sources.

4.3.2. Principle Component and Cluster Analyses

Principle Component Analysis (PCA) was introduced by Pearson (1901) and later developed by Hotelling (1933). It is one of the oldest multivariate techniques. PCA allows to reduce the dimensionality of a data set in which there is a large number of interrelated variables, while retaining as much as possible of the variation present in the data set (Jolliffe, 1986). This methodology is applied to a data table where rows are individuals and columns are variables.

The maritime routes between each pair of ports (port of departure and port of arrival) are considered as active individuals, i.e contributing to the estimated inertia of the cloud of individuals. The following continuous and discrete variables play the role of active elements in the analysis: Avg_TEU, Ships, Carriers, Trips, Distance, Carriers_ships and LSBCI, meaning that the inertia (or variance) of the cloud of variables is calculated on the mere basis of these active variables. Supplementary elements are also included but do not contribute directly to the factor analysis, being simply projected on the factorial maps built up by active elements: Route_Country, Route_Continents, Route_Regions and Trade_Direction, playing the role of illustrative discrete variables. The supplementary elements make it possible to illustrate the principal components.

We have also divided the maritime routes into different clusters by applying the Hierarchical Agglomerative Clustering Analysis based on prior Principle Components. The distance between the clusters has been computed by the Ward's Method (Ward Jr, 1963).

4.4. Results

This part describes the results of the study. The first section provides descriptive statistics related to the whole dataset of 6,410 maritime routes. In the second and third sections are depicted the results of the PCA and cluster analyses for a subset of 3,054 maritime routes. A brief summary of the typology of the maritime routes is presented in the fourth part. Finally, a summary of the outcomes of an analysis of 800 highly competitive routes by applying exactly the same approach are shown.

4.4.1. Descriptive statistics

By looking first at the whole sample, we analyze the degree of competition on 6,410 maritime routes connecting 153 ports from 50 countries. Table 4.3 provides descriptive statistics of the variables used in this study:

Table 4.3 Descriptive statistics for the whole dataset (6,410 routes)

Variable name	Count	Mean	Std. Deviation	Minimum	Maximum
TEU	6,410	4,299.77	3,015.23	80.00	18,270.00
Ships	6,410	25.20	54.07	1.00	1,237.00
Carriers	6,410	11.14	17.90	1.00	264.00
Trips	6,410	99.70	277.10	1.00	5,510.00
Distance	6,410	6,771.12	5,906.48	0.00	22,374.60
Ships_per_carrier	6,410	1.86	1.21	1.00	19.00
LSBCI	5,630	0.55	0.15	0.19	0.86

Source: Authors' calculations

As we can see in Table 4.3, the dataset contains heterogeneous maritime routes. There are routes with only one ship operating between the port of origin and the port of arrival. The average size of ships, which is a proxy for economies of scale, also varies significantly: the mean is 4,299.77 and the maximum value is 18,270. On average, there are 25 ships and 99.7 trips per route. The average number of ships per carrier is 1.86, but some carriers can deploy up to 19 ships on a single route. Unfortunately, the distribution of market shares per route between operators, which would allow calculation for the classical concentration indicator, was not available in this dataset. The high mean value of LSBCI (0.55) indicates that countries in the sample are relatively well connected between each other.

Table 4.4: Pearson's correlation matrix of the variables related to 6,410 routes

	Avg_TEU	Ships	Carriers	Trips	Distance	Ships_per_carrier	LSBCI
TEU	1.000						
Ships	0.128	1.000					
Carriers	0.018	0.921	1.000				
Trips	-0.044	0.604	0.711	1.000			
Distance	0.592	-0.081	-0.165	-0.156	1.000		
Ships_per_carrier	0.407	0.328	0.205	0.165	0.191	1.000	
LSBCI	0.283	0.278	0.242	0.213	0.042	0.227	1.000

Source: Authors' calculations

There is a predictable strong correlation between the number of carriers and that of ships. Also not surprising is the high positive correlation between the latter and the number of trips. However, the positive correlation coefficient between Distance and Avg_TEU indicates that the average size of operating ships increases with the distance between the port of origin and destination. Economies of scale would therefore increase with distance and may reduce the number of competing carriers. The number of ships per carrier, which is a proxy for the size of shipping companies, is also higher on the routes where these big vessels operate. Distance between ports is therefore a variable having a substantial effect on the level of competition.

Regarding the regional container trade, there are some fundamental differences across regions. In the dataset, the maritime routes are well distributed between “Developed” and “Less developed” countries. There are 1,766 routes between Developed countries (D-D), 1,414 routes connecting “Developed” and “Less Developed” states (D-LD), 1,447 routes between Less Developed and Developed nations (LD-D) and 1,783 routes link exclusively Less Developed states (LD-LD).

Table 4.5: Mean values according to the trade direction.

	Mean (D-D)	Mean (D-LD)	Mean (LD-D)	Mean (LD-LD)
Avg_TEU	5,073.47	4,683.84	4,725.07	2,883.67
Ships	30.52	24.81	24.49	20.82
Carriers	12.86	10.97	10.86	9.81
Trips	145.59	91.71	93.17	65.87
Distance	7,298.05	7,921.28	7,575.73	4,684.00
Ships_per_carrier	2.21	1.80	1.84	1.51
LSBCI	0.61	0.55	0.55	0.48

Source: Authors' calculations

Note: D refers to “Developed” countries and LD refers to “Less Developed” ones. Developed states are those considered as “high income” countries by the World Bank while all the others are considered as Less Developed countries in this study.

Table 4.5 reveals the relative imbalance according to the level of income of the countries in the sample. The mean values of all variables are the highest on the maritime routes connecting

“Developed” states (DD). It indicates that on these routes, the relative connectivity of the ports is also high and the traffic is the most intensive. The average size of operators is also greater (2.21 ships per operator), which indicates more concentrated markets.

On the other hand, the containerized trade among “Less Developed” (Low income, Lower middle income, and Upper middle income countries) is less concentrated and the average values of all variables are the lowest ones. It is interesting to highlight that the maritime routes D-LD and LD-D are not perfectly symmetrical. The average size of ships on the “D-LD” routes is smaller and their number is slightly higher than those operating on the “LD-D” routes. This indicates a regional misbalance of the trade going from “Developed” to “Less developed” countries and vice versa. The services on the “LD-D” routes are more frequent and the vessels are smaller. In addition, there are more carriers on the “D-LD” routes. It could be explained by the fact that often the vessels are not fully loaded in the ports in developed countries due to the low demand in less developed states. As a consequence, some carriers cooperate by forming alliances in order to optimize their costs.

When we look at the trade between continents, we observe that the container trade patterns differ considerably. Table 4.6 shows that the biggest vessels operate between Europe and Asia. The average distance of these routes is also the longest. In addition, on average the vessels on Europe-Asia are with 269 TEUs bigger than those on Asia-Europe routes.

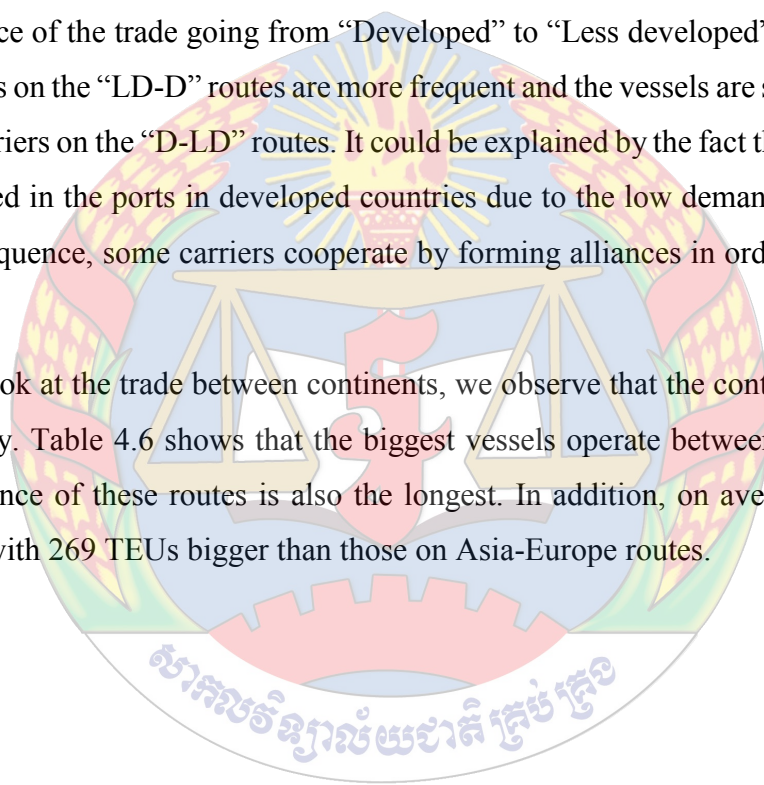


Table 4.6: Average values according to the continents of origin and destination

Route	Mean Avg. TEU	Mean Ships	Mean Carriers	Mean Trips	Mean Distance	Mean Ships_per_carrier	Mean LSBCI
Eur-Asia	8,757.19	25.01	7.25	59.34	14,623.46	2.80	0.62
Asi-Eur	8,488.66	27.99	7.96	73.03	13,708.51	2.76	0.62
Ame-Asia	5,698.62	21.24	9.06	56.06	13,452.31	2.04	0.58
Asia-Ame	5,697.69	24.30	10.28	67.28	12,569.75	2.00	0.59
Afr-Asia	5,474.79	28.33	10.58	65.51	11,881.27	1.68	0.42
Asia-Afr	5,398.96	26.42	11.26	64.41	10,587.49	1.82	0.43
Afr-Ame	4,800.08	9.58	5.14	24.91	10,586.55	1.48	0.47
Eur-Ame	4,469.81	16.49	7.77	59.49	8,805.08	1.99	0.57
Ame-Eur	4,419.10	15.80	7.31	56.27	8,708.18	2.06	0.58
Eur-Eur	4,241.52	54.07	23.23	328.18	2,306.26	2.04	0.66
Ame-Afr	4,206.42	11.60	5.65	30.13	10,785.53	1.49	0.44
Ame-Ame	3,912.69	23.15	11.14	87.91	2,794.57	1.78	0.50
Eur-Afr	3,343.37	23.76	11.20	98.68	3,423.56	1.75	0.46
Afr-Eur	2,969.62	18.10	10.46	87.06	3,495.96	1.54	0.45
Asia-Asia	2,497.50	27.44	13.10	125.96	2,704.49	1.55	0.56
Afr-Afr	1,718.72	12.01	8.10	44.87	2,275.70	1.45	0.33

Source: Authors' calculations

A significant difference is observed between routes by number of trips. On Asia-Europe routes, the mean value of trips is 73 while on Europe-Asia ones it is only 59, due the imbalance of trade between the two zones. A similar asymmetric pattern characterizes the Asia-America route, with 67 trips and 24 ships on the front haul, against 56 trips and 21 ships on the back haul. However, the average size of companies measured in TEU per ship or in number of ships per company is very similar, unlike the Europe-Asia trade where, curiously, the average size of firms and vessels is slightly higher on the back haul (Europe to Asia) despite the imbalance. Almost symmetrical figures are reported on the routes between Europe and America. It indicates that the demand for container services is almost the same in the two continents. This trade balance facilitates carriers to operate efficiently, with an average firm size around 2 ships per carrier in both ways.

The intra-Asian and intra-African routes have different patterns. The average size of vessels as well as their absolute concentration measured by the number of ships per carrier is smaller than the intra-European and intra-American routes. The frequency of trips is fairly high on the intra-Asian trade routes compared to the intra-American trade, with 126 trips on average against 88, but both are far smaller than intra-European trade routes. Smaller vessels (1,719 TEU) operate on the intra-continental routes in Africa, where the bilateral connectivity between African countries is the lowest of the sample. Conversely, intra-Asian containerized trade is conducted between countries having a high connectivity. Appendix 4.A depicts the maritime routes according to the region of origin and destination. Results show that the biggest vessels are deployed on the routes between East Asia, South-East Asia, Eastern Europe and Western Europe. On these routes, the average number of ships per vessels is the highest.

In summary, the overview of the 6,410 maritime routes shows that there exists a significant misbalance between developed and less developed countries across regions. Maritime routes where larger companies compete (i.e. with a higher number of ships per carrier) are mainly associated with long distances and inter-regional trade between developed and less developed countries. Countries that are poorly connected tend to have a lower absolute concentration. In addition, intra-continental trade is more developed between High Income countries and, as a consequence, their connectivity is also high. The market concentration (number of ships per carrier) is the highest on the routes connecting Developed (High income) countries and lowest on the links between “Less Developed” ones. The trade routes “D-LD” and “LD-D” are not symmetrical, which indicates a misbalance within the industry. When we look at the continent of origin and destination, it seems that the highest disparities are on the routes between Europe and Asia, and America and Asia. This regional imbalance explains the strategies of shipping companies to deploy bigger ships and to decrease the trips on the back haul routes from Europe and America to Asia.

4.4.2. Principle Component Analysis (PCA)

The descriptive analysis in the previous part allowed us to have a global view of the maritime route connecting the 153 ports in the sample with respect to the selected seven variables. In order to reduce the dimensionality of the data by keeping the most of the information, the Principle Component Analysis (PCA) has been applied. This method allows us to transform a number of correlated variables into a number of uncorrelated variables, also known as “principle components”. In order to include the routes with regular services, we removed from the sample routes with fewer than 12 trips. We also excluded routes connecting ports from the same country. Thus, the final sample that will be analyzed by using the multivariate approach consists of 3,054 routes. As active variables included in the PCA, we use Avg_TEU, Ships, Carriers, Trips, Distance, Ships_per_carrier and LSBCI. The supplementary variables are the following: Route_Country, Route_Continents, Route_Regions and Trade_Direction.

Table 4.7 shows the descriptive statistics for the sample of 3,054 maritime routes. The dataset contains very heterogeneous routes. The size of the ships varies considerably. Despite the fact that we take into account only routes with at least 12 trips, we still have routes dominated by only one container carrier.

Table 4.7 Descriptive Statistics for active variables used for the PCA

Variable	Count	Mean	Standard deviation	Minimum	Maximum
Avg_TEU	3,054	4,859.31	2,983.49	230.00	16,948.00
Ships	3,054	40.19	51.25	1.00	716.00
Carriers	3,054	17.27	17.75	1.00	214.00
Trips	3,054	152.61	252.86	12.00	2,630.00
Distance	3,054	7,446.68	5,521.92	38.35	22,052.80
Ships_per_carrier	3,054	2.40	1.37	1.00	19.00
LSBCI	3,054	0.57	0.13	0.20	0.86

Source: Authors' calculations

Table 4.8 Pearson's correlations matrix for active variables used for PCA

Variables	Avg_TEU	Ships	Carriers	Trips	Distance	Ships_per_carrier	LSBCI
Avg_TEU	1.00						
Ships	0.17	1.00					
Carriers	-0.06	0.90	1.00				
Trips	-0.09	0.66	0.73	1.00			
Distance	0.64	-0.04	-0.20	-0.20	1.00		
Ships_per_carrier	0.59	0.20	-0.05	0.03	0.41	1.00	
LSBCI	0.29	0.33	0.25	0.23	0.03	0.23	1.00

Source: Authors' calculations

The correlation coefficients of the active continuous and discrete variables are similar to the coefficients for the whole dataset of 6410 ports (see Table 4.4). However, the correlation between the ships and carriers is lower in this subset of data. In addition, the trips and ships seem to have a stronger positive relation. The correlation coefficient of Avg_TEU and Ships_per_carrier as well as Avg_TEU and Distance are higher than those related to the previous dataset. When we conduct the Principle Component Analysis, all variables are standardized.

Table 4.9: Explained variance by component in the PCA analysis

Axis	Variance of the axis (eigenvalue)	% of explained variance	Cumulated % of explained variance	Retained according to Kaiser's criterion
1	2.705	38.6	38.6	X
2	2.223	31.8	70.4	X
3	0.818	11.7	82.1	
4	0.555	7.9	90.0	
5	0.368	5.3	95.3	
6	0.271	3.9	99.1	
7	0.061	0.9	100.0	
Total	7.000	100.0	100.0	

Source: Authors' calculations

First we study the inertia of the principle components by analyzing the inertia intercepted by the factorial axe. Table 4.9 shows the Eigenvalues associated with each component, the percentage of explained variance and the cumulated percentage.

Following the Kaiser's criterion, we have decided to retain the first two components. Their cumulative percentage of explained variance is 70.4%.

Next we evaluate the contribution and correlation of active variables to each of the two retained components. As shown in Table 4.10, Ships, Carriers and Trips have very strong correlation with the first component, while Avg_TEU, Distance and Ships_per_carrier are associated with the second component. LSBCI does not play a very important role in the construction of the components.

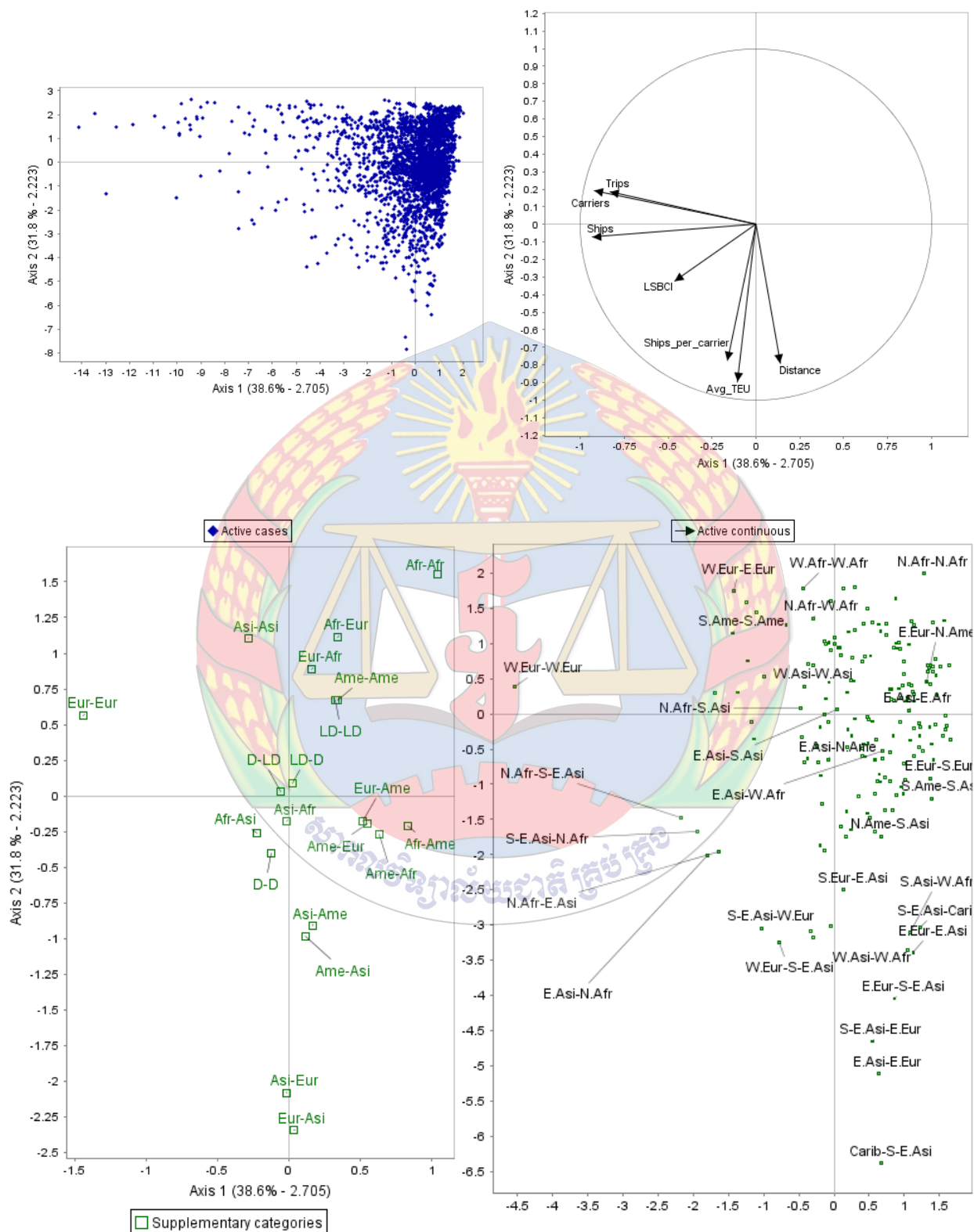
Table 4.10: Correlation coefficients of active variables with the axis and the contribution of the active variables to the axis

	Correlations between active variables and factors		Contributions of the active variables to the axes (in %)	
	Axis 1	Axis 2	Axis 1	Axis 2
Avg_TEU	-0.105	-0.897	0.4	36.2
Ships	-0.935	-0.074	32.3	0.2
Carriers	-0.926	0.193	31.7	1.7
Trips	-0.836	0.186	25.8	1.6
Distance	0.138	-0.793	0.7	28.3
Ships_per_carrier	-0.165	-0.778	1.0	27.2
LSBCI	-0.466	-0.325	8.0	4.8

Source: Authors' calculations

Therefore, the first component is related to the market size in terms of traffic and frequency of services, while the second component is associated with the increasing returns to the scale of a small number of carriers facing long distance trade. Dropping the LSBCI variable and retaining the whole sample in the analysis, which is not presented here to avoid tedious representation, these two dimensions appear even more clearly: the first component captures the number of ships, trips and ships per operator, while the second axis introduces the negative correlation between the distance (associated with the average size of ships) and the number of carriers. Long distance hauls command the absolute concentration of the market, with fewer and larger operating carriers.

Figure 4.1: Graphical representation of individuals, active variables and supplementary variables



Source: Authors' calculations and visualization

Note: In the upper-left corner: the factorial map of individuals; in the upper- right corner: representation of the active continuous variables; in the lower-left corner: representation of the supplementary categorical variables related to the Trade Direction and the Trade between continents; in the lower-right corner: representation of the supplementary categorical variables related to trade between regions.

The upper-left corner in Figure 4.1. shows the distribution of the maritime routes, while the upper-right corner depicts active variables as well as the two retained components. The graph illustrates clearly that the first component is related to the frequency of services, while the second one is related to the economies of scale. By looking at the lower-left corner, we can see the representation of the maritime routes in terms of continent of origin and destination as well as the direction of the trade according to the income of the countries defined by the World Bank. For instance, the first basic component shows that intra-European routes have more trips, ships and carriers (main active variables explaining the first component) than the intra-African and Africa-America ones. For this reason they are situated at the opposite ends of the horizontal axis. The second component (the vertical axis) opposes mainly long distance routes, i.e. Europe-Asia, America-Asia with short-distance ones, i.e. intra-Asian and Africa-Europe.

In the sample, there are 205 unique maritime routes connecting different regions. Some of them are depicted in the lower-right corner in Figure 4.1. It becomes clearer that in the maritime trade there are substantial disparities across regions. A regional trade that is closer to the mean values for the whole dataset is between East Asia and South Asia. We can see clearly the similarities between intra-regional routes such as intra-West African, intra-South American, Western Europe and Eastern-Europe. Similarly, long distance routes South-Eastern Asia - Western Europe, Southern Europe - Eastern Asia, Eastern Europe - South-Eastern Asia also have similar features. It should be noted, however, that in case we have more than two retained components, it is necessary to create graphs with multiple dimensions which makes the graphical representation challenging.

PCA allows us to retain two components. The illustrative variables show that maritime routes have different characteristics. Therefore, it seems useful to define different clusters based on the PCA active variables and described by both active and supplementary variables.

4.4.3. Cluster Analysis

The purpose of the Cluster Analysis is to classify a set of objects. The hierarchical method consists of agglomerating individuals which have similar or close values on active variables. This “cluster” is treated as one individual in a new matrix. This process continues until the optimal number of clusters is found and retained. To visualize these clusters, we build a hierarchical tree called dendrogram (see Figure 4.4).

This tree can be considered a sequence of nested partitions from the most precise (in which each individual is a class), to the most general one (in which there is only one class where all inertia is lost) (Husson et al., 2017). As in the previous section, we have used the same sample (3,054 maritime routes) to conduct the clustering analysis.

Table 4.11 Indicators of the quality of the identified clusters following Agglomerative Hierarchical Clustering

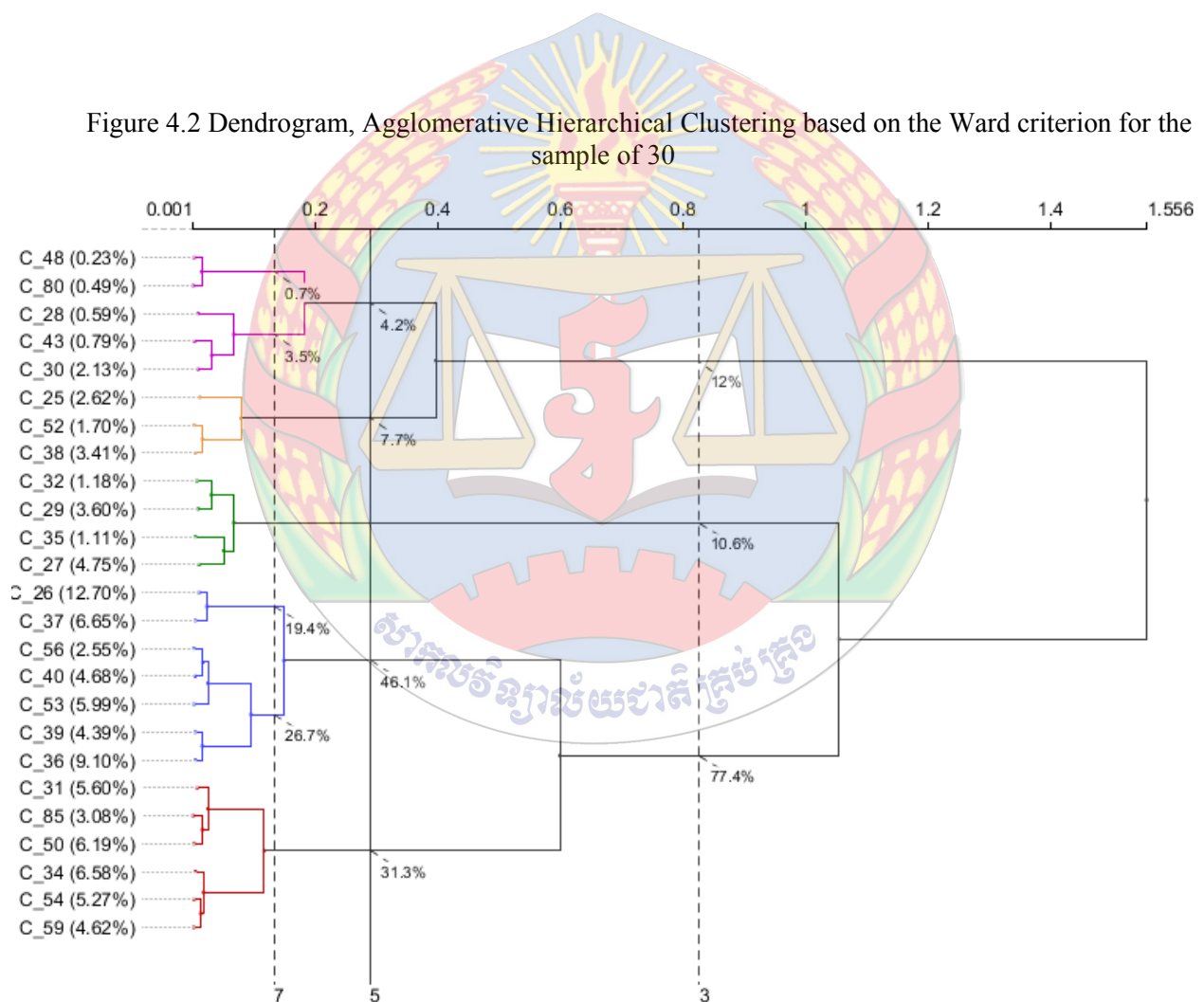
Criteria	3 clusters	4 clusters	5 clusters	6 clusters	6 clusters	6 clusters
Intra-cluster inertia	2.317	1.719	1.322	1.139	0.989	0.873
Inter-cluster inertia	2.610	3.209	3.605	3.789	3.938	4.055
Explained inertia (%)	52.969	65.122	73.171	76.893	79.919	82.290
Calinski-Harabasz (pseudo F) criterion	1718.105	1898.220	2078.847	2028.523	2021.068	2021.898
Davies-Bouldin's index	0.812	0.824	0.891	0.860	0.947	0.935

Source: Authors' calculations

Table 4.11 depicts some metrics related to the optimal number of clusters. The objective is to have clusters that are clearly distinguished (having high inter-cluster inertia). The Calinski-Harabasz criterion (or pseudo F) allows us to measure the gap between all the clusters. A higher value means that the clusters are well differentiated. Thus, according to this index, the optimal number of clusters is five.

In addition, to form a cluster, the individuals should have similar characteristics (low intra-cluster inertia). The Davies-Bouldin index is based on intra-cluster dispersion ratio minimization and inter-cluster separation (Coheris Analytics SPAD, 2018). Lower index means that the clusters are more compact. This index suggests that three or six clusters comprise the optimal number.

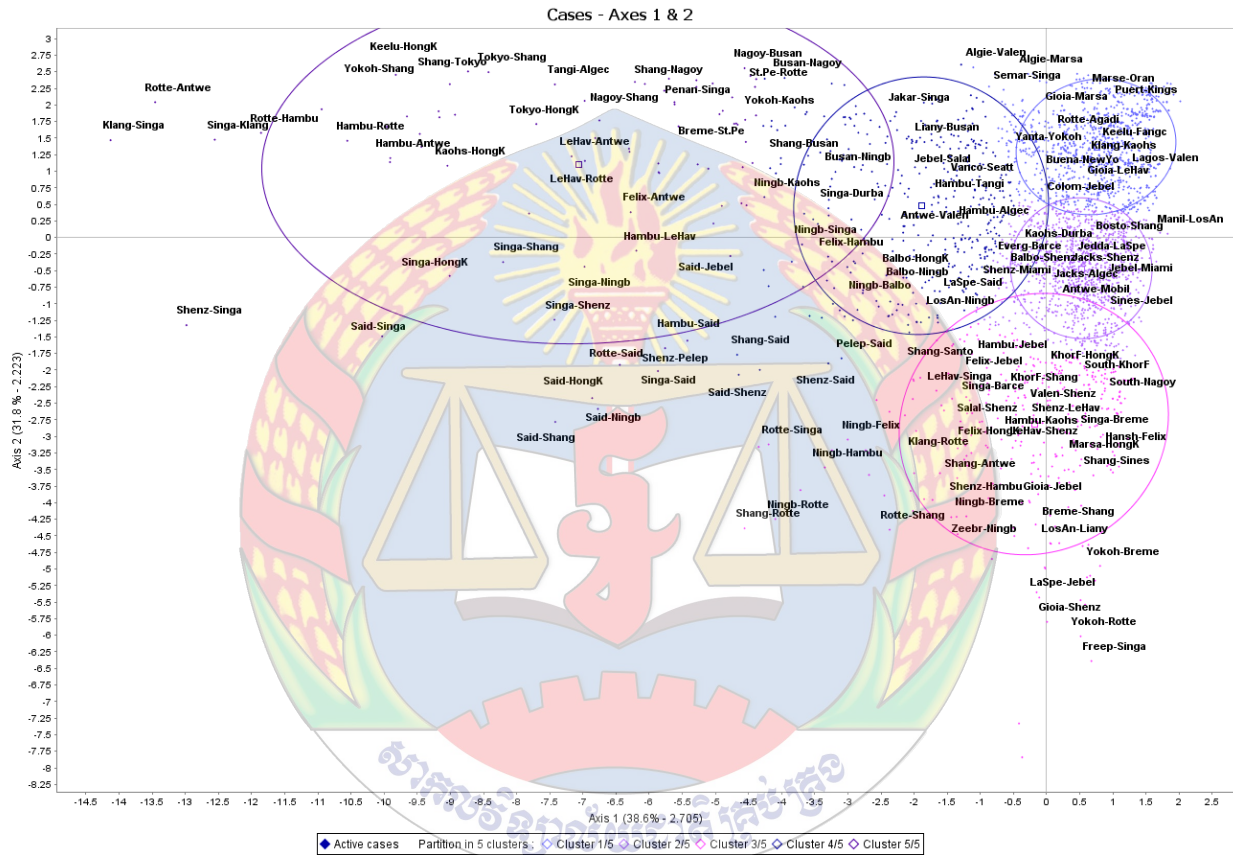
By looking at the optimum number that the two Calinski-Harabasz criteria and Davies-Bouldin's index show, as well as the percentage of explained inertia, we observe that by increasing the number of clusters from five to six, the gain of inertia is less than 3%. Therefore, the optimum number of clusters seems to be five.



Source: Authors' calculations and visualization

Figure 4.2 shows the Hierarchical tree (Dendrogram) of the 3,054 maritime routes. By choosing to retain five clusters, we explain 73.17% of the total variability. These clusters are depicted on the two axes that we have retained following the PCA (Figure 4.3).

Figure 4.3 Graphical representation of the four clusters on the first two PCA axes, clearer representation is in Appendix 4.B



Source: Authors' calculations and visualization

As we can see in the figure above as well as in Appendix 4.B, in the barycenter of cluster 1 is the maritime route connecting Port Klang, Malaysia and Port of Kaohsiung, Taiwan. In 2014, between these two ports there were 12 ships with an average size of 1,511 TEU and 1.5 ships per carrier were operating. A typical representative of cluster two is the maritime connection between Jacksonville, U.S. and Shenzhen, China. There were 17 ships with a mean size of 4,988 TEU which conducted 37 trips. Cluster three is represented by routes similar to the one linking Hamburg,

Germany and Shenzhen, China (Avg_TEU =9775 TEU, Ships=69, Carriers = 16, Trips = 154 and Distance =19,486 nautical miles, Ships_per_carrier = 4.31). The closest maritime route to the barycenter of the fourth cluster is the Antwerp (Belgium)–Valencia (Spain) route with the following specifications: Avg_Teu = 4,567, Ships = 77, Carriers = 28, Trips 458, Distance = 2,442 and Ships_per_carrier = 2.75. The last cluster is characterized by a high degree of competition (many operators, trips and ships) and the maritime route which has the closest values to the means of this cluster is Le Havre (France)-Rotterdam (Netherlands). There are 215 ships with an average size of 4,001 TEU, 96 carriers and 2.24 ships per carrier.

Some outliers and maritime routes close to the center of gravity of each cluster are shown as well. In order to have a better idea about the general characteristics of the five clusters, we provide the most significant statistics sorted out by a mean test for each one of them.

4.4.3.1. Cluster 1, mainly intra-Asian routes, low level of market concentration (1,000 maritime routes)

The first cluster includes 1,000 maritime routes and is linked mainly to the first component (see Appendix 4.B). It is characterized by all seven active variables. Their mean values are lower than the average values of the whole dataset. Thus, we can conclude that this cluster combines mainly short-distance maritime routes with relatively low level of concentration of competition (ships per carrier is 1.45), not many trips, relatively low level of connectivity and smaller vessels operating. Table 4.12.

Table 4.12 Cluster 1 descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
Trips	88.52	152.61	95.97	252.82	-9.77	0.00
Carriers	12.07	17.27	7.95	17.75	-11.29	0.00
Ships	17.92	40.19	12.50	51.24	-16.76	0.00
LSBCI	0.50	0.57	0.14	0.13	-20.59	0.00
Ships_per_carrier	1.50	2.40	0.45	1.37	-25.41	0.00
Distance	3,252.36	7,446.69	2,559.16	5,521.01	-29.29	0.00
Avg_TEU	2,158.31	4,859.31	1,199.44	2,983.00	-34.91	0.00

Source: Authors' calculations

Note: The test Value plays the role of a criterion that distinguishes the variables which play an essential role in the interpretation of the groups. Negative value of Test-value means that the active variable is under-presented (its mean is lower than the mean value of the whole dataset). A positive Test-value shows that the active variable is over-presented (its mean is higher than the mean value of the whole dataset).

Table 4.13 Cluster 1, descriptive statistics of the supplementary variables

Variable label	Characteristic categories	% of category in group	% of category in set	% of group in category	Test-value	Probability	Weight
Route_Continents	Asi-Asi	47.2	24.5	63.0	19.820	0.000	749
Route-regions	S-E.Asi-S-E.Asi	12.2	4.6	87.8	13.752	0.000	139
Trade_direction	LD-LD	26.8	15.6	56.4	11.563	0.000	475
Route-regions	E.Asi-S-E.Asi	8.7	3.9	72.5	9.008	0.000	120
Route-regions	S-E.Asi-E.Asi	9.5	4.5	69.3	8.887	0.000	137
Route-regions	E.Asi-E.Asi	13.4	7.3	60.4	8.706	0.000	222
Route_Continents	Afr-Eur	8.4	4.3	63.6	7.344	0.000	132
Route_Continents	Eur-Afr	8.1	4.4	60.0	6.558	0.000	135
Route_Continents	Ame-Ame	12.7	7.9	52.5	6.543	0.000	242
Route_Country	JPN-CHN	4.5	2.1	71.4	6.221	0.000	63
Trade_direction	LD-D	30.9	25.0	40.4	5.108	0.000	765
Trade_direction	D-LD	30.4	25.9	38.4	3.856	0.000	792

Source: Authors' calculations

Note: The table shows only the categorical variables that are significant and over-presented in the sample (having positive Test-value). The first column represents “% of category in group” the percentage of the routes in the identified cluster (group) that have a given characteristic. The second column “% of category in set” refers to the percentage of the whole category in the whole sample (set). The third column “% of group in category” depicts the percentage of the Characteristic Category belonging to the identified cluster (group). The test Value plays the role of a criterion that distinguishes the variables that play an essential role in the interpretation of the groups. The last column “Weight” shows the importance of each variable within the cluster.

Table 4.13 shows the significant supplementary variables. 47.2% of the routes in this cluster are intra-Asian, especially between Japan and China. 26.8% are between less developed countries while those connecting less developed states with developed ones and vice-versa account for 30.9% and 30.4% of the cluster, respectively. In addition, Europe-Africa routes represent 16.5%.

4.4.3.2. Cluster 2, Maritime routes connecting Europe-America and America-Asia, moderate level of market concentration (1,206 maritime routes)

The second cluster is the biggest one and has 1,206 routes. This cluster is situated on the intersection between the two principle components. All active variables except LSBCI and Ships_per_carrier are significant. The routes are slightly longer than the whole sample mean (9,777.38 nautical miles) and characterized by a few carriers operating and deploying closer to the average size of vessels (Avg_TEU is 5,680 TEU). Even though the variable ships_per_carrier, it is not significant at the level of 0.05, its average is closer to the mean. Thus, on these routes, there is a moderate market absolute concentration.

Table 4.14 Cluster 2, descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
Distance	9,773.38	7,446.69	4,145.49	5,521.01	18.81	0.00
Avg_TEU	5,680.20	4,859.31	1,615.62	2,983.00	12.28	0.00
Ships	25.38	40.19	14.40	51.24	-12.90	0.00
Trips	74.55	152.61	57.65	252.82	-13.78	0.00
Carriers	11.21	17.27	6.50	17.75	-15.23	0.00
Ships_per_carrier*	2.435	2.398	0.814	1.369	1.186	0.118

Source: Authors' calculations

Note: The test Value plays the role of a criterion that distinguishes the variables which play an essential role in the interpretation of the groups. Negative value of Test-value means that the active variable is under-presented (its mean is lower than the mean value of the whole dataset). A positive Test-value shows that the active variable is over-presented (its mean is higher than the mean value of the whole dataset). Ships_per_carrier is not significant at the level of 0.05.

Table 4.15 Cluster 2, descriptive statistics of the supplementary variables

Characteristic categories	% of category in group	% of category in set	% of group in category	Test-value	Probability	Weight
D-D	48.8	33.5	57.5	14.37	0.00	1022
Ame-Eur	14.7	7.7	75.0	11.47	0.00	236
Eur-Ame	14.3	7.6	73.8	11.00	0.00	233
Asi-Ame	13.2	7.0	74.0	10.56	0.00	215
Ame-Asi	12.4	6.9	70.8	9.48	0.00	212
E.Asi-N.Ame	6.7	3.5	75.7	7.65	0.00	107
N.Ame-W.Eur	5.3	2.6	80.0	7.38	0.00	80
N.Ame-S.Eur	4.6	2.2	83.3	7.27	0.00	66
W.Eur-N.Ame	4.9	2.4	79.7	7.03	0.00	74
N.Ame-E.Asi	6.5	3.5	72.2	6.91	0.00	108
S.Eur-N.Ame	4.3	2.2	77.6	6.30	0.00	67

Source: Authors' calculations

Note: The table shows only the categorical variables that are significant and over-presented in the sample (having positive Test-value). The first column represents “% of category in group” the percentage of the routes in the identified cluster (group) that have a given characteristic. The second column “% of category in set” refers to the percentage of the whole category in the whole sample (set). The third column “% of group in category” depicts

the percentage of the Characteristic Category belonging to the identified cluster (group). The test Value plays the role of a criterion that distinguishes the variables that play an essential role in the interpretation of the groups. The last column “Weight” shows the importance of each variable within the cluster.

From a regional perspective, this cluster gathers nearly all front and back hauls between Europe and America as well as America and Asia.

4.4.3.3. Cluster 3, Europe-Asia routes, low degree of competition (377 maritime routes)

The third cluster is situated on the second axis and has 377 maritime routes. The market concentration in this cluster is the highest (4.65 ships per carrier). These are long distance routes connecting well interconnected countries (LSBCI is 0.65) where mainly large vessels operate (around 10,019 TEUs). The number of trips and carriers in this cluster are lower than the average for the whole dataset, even though the number of ships is slightly higher than the sample mean.

Table 4.16. Cluster 3, descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
Avg_TEU	10,019.300	4,859.310	2388.540	2,983.000	35.868	0.000
Ships_per_carrier	4.652	2.398	2.129	1.369	34.130	0.000
Distance	15,035.500	7,446.690	4,482.650	5,521.010	28.501	0.000
LSBCI	0.646	0.572	0.094	0.132	11.513	0.000
Ships	48.804	40.194	39.363	51.244	3.484	0.000
Trips	122.830	152.607	113.329	252.819	-2.442	0.007
Carriers	12.037	17.269	9.085	17.748	-6.113	0.000

Source: Authors' calculations

Note: The test Value plays the role of a criterion that distinguishes the variables which play an essential role in the interpretation of the groups. Negative value of Test-value means that the active variable is under-presented (its mean is lower than the mean value of the whole dataset). A positive Test-value shows that the active variable is over-presented (its mean is higher than the mean value of the whole dataset).

Table 4.17. Cluster 3, descriptive statistics of the supplementary variables

Characteristic categories	% of category in group	% of category in set	% of group in category	Test-value	Probability	Weight
Eur-Asi	38.7	6.9	69.5	20.467	0.000	210
Asi-Eur	29.4	6.6	55.0	15.300	0.000	202
D-LD	31.3	25.9	14.9	2.442	0.007	792

Source: Authors' calculations

Note: The table shows only the categorical variables that are significant and over-presented in the sample (having positive Test-value). The first column represents “% of category in group” the percentage of the routes in the identified cluster (group) that have a given characteristic. The second column “% of category in set” refers to the percentage of the whole category in the whole sample (set). The third column “% of group in category” depicts the percentage of the Characteristic Category belonging to the identified cluster (group). The test Value plays the role of a criterion that distinguishes the variables that play an essential role in the interpretation of the groups. The last column “Weight” shows the importance of each variable within the cluster.

The supplementary variables for this cluster reveal that 68.1% of the routes in this cluster are between Europe and Asia. These results are consistent with the descriptive analysis that we have done in the descriptive analysis of the whole sample of 6,410 individuals.

4.4.3.4. Cluster 4, Divers routes, moderate level of competition (390 maritime routes)

The fourth cluster contains 390 routes. This cluster is mainly linked with the first axis. These routes are to a large extent regional ones (Distance is 4,600 nautical miles) between well interconnected countries (LSBCI is 0.64). The average size of the containerships is lower than the average while the number of trips and ships operating on the routes are significantly higher.

Table 4.18. Cluster 4, descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
Carriers	39.84	17.27	13.14	17.75	26.89	0.00
Ships	92.23	40.19	38.39	51.24	21.47	0.00
Trips	361.11	152.61	227.86	252.82	17.44	0.00
LSBCI	0.64	0.57	0.11	0.13	11.19	0.00
Avg_TEU	4,443.48	4,859.31	2,063.76	2,983.00	-2.95	0.00
Distance	4,646.46	7,446.69	4,169.60	5,521.01	-10.72	0.00
Ships_per_carrier*	2.338	2.398	0.664	1.369	-0.924	0.178

Source: Authors' calculations

Note: The test Value plays the role of a criterion that distinguishes the variables which play an essential role in the interpretation of the groups. Negative value of Test-value means that the active variable is under-presented (its mean is lower than the mean value of the whole dataset). A positive Test-value shows that the active variable is over-presented (its mean is higher than the mean value of the whole dataset). Ships_per_carrier is not significant at the level of 0.05.

Table 4.19. Cluster 4, descriptive statistics of the supplementary variables

Characteristic categories	% of category in group	% of category in set	% of group in category	Test-value	Probability	Weight
Eur-Eur	17.9	7.3	31.3	7.522	0.000	224
E.Asi-E.Asi	15.6	7.3	27.5	6.055	0.000	222
Asi-Asi	33.6	24.5	17.5	4.271	0.000	749
N.Ame-E.Asi	6.4	3.5	23.1	2.920	0.002	108

Source: Authors' calculations

Note: The table shows only the categorical variables that are significant and over-presented in the sample (having positive Test-value). The first column represents “% of category in group” the percentage of the routes in the identified cluster (group) that have a given characteristic. The second column “% of category in set” refers to the percentage of the whole category in the whole sample (set). The third column “% of group in category” depicts the percentage of the Characteristic Category belonging to the identified cluster (group). The test Value plays the role of a criterion that distinguishes the variables that play an essential role in the interpretation of the groups. The last column “Weight” shows the importance of each variable within the cluster.

The routes in the cluster are mainly intra-European and intra-Asian. They account for 51.5% of the cluster.

4.4.3.5. Cluster 5, Moderate level of competition, intra Europe and Intra-Asia (81 maritime routes)

The last identified cluster is the smallest one and similarly to the previous cluster, it is situated mainly on the first axis. Surprisingly, the level of competition is slightly higher than the average (2.79 ships per carrier), while the number of trips, ships and carriers is significantly higher. This is especially true for the average number of ships, 1,240 trips on a single road.

Table 4.20. Cluster 5, descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
Trips	1,240.64	152.61	631.09	252.82	39.25	0.000
Ships	245.09	40.19	122.20	51.24	36.47	0.000
Carriers	87.25	17.27	29.90	17.75	35.96	0.000
LSBCI	0.71	0.57	0.11	0.13	9.81	0.000
Ships per carrier	2.79	2.40	1.10	1.37	2.64	0.004
Avg TEU	3,969.00	4,859.31	2,483.22	2,983.00	-2.72	0.003
Distance	2,748.36	7,446.69	3,106.97	5,521.01	-7.76	0.000

Source: Authors' calculations

Note: The test Value plays the role of a criterion that distinguishes the variables which play an essential role in the interpretation of the groups. Negative value of Test-value means that the active variable is under-presented (its mean is lower than the mean value of the whole dataset). A positive Test-value shows that the active variable is over-presented (its mean is higher than the mean value of the whole dataset).

Table 4.21. Cluster 5, descriptive statistics of the supplementary variables

Characteristic categories	% of category in group	% of category in set	% of group in category	Test-value	Probability	Weight
Eur-Eur	34.6	7.3	12.5	7.139	0.000	224
E.Asi-E.Asi	33.3	7.3	12.2	6.890	0.000	222
Asi-Asi	48.1	24.5	5.2	4.563	0.000	749
JPN-CHN	9.9	2.1	12.7	3.535	0.000	63
D-LD	37.0	25.9	3.8	2.124	0.017	792
Afr-Asi	7.4	2.8	7.1	1.981	0.024	85

Source: Authors' calculations

Note: The table shows only the categorical variables that are significant and over-presented in the sample (having positive Test-value). The first column represents “% of category in group” the percentage of the routes in the identified cluster (group) that have a given characteristic. The second column “% of category in set” refers to the percentage of the whole category in the whole sample (set). The third column “% of group in category” depicts the percentage of the Characteristic Category belonging to the identified cluster (group). The test Value plays the role of a criterion that distinguishes the variables that play an essential role in the interpretation of the groups. The last column “Weight” shows the importance of each variable within the cluster.

This cluster is almost entirely made by intra-European and Intra-Asian routes (82.7%). As we can see in Appendix 4.B, the maritime connections between China and Japan are significant.

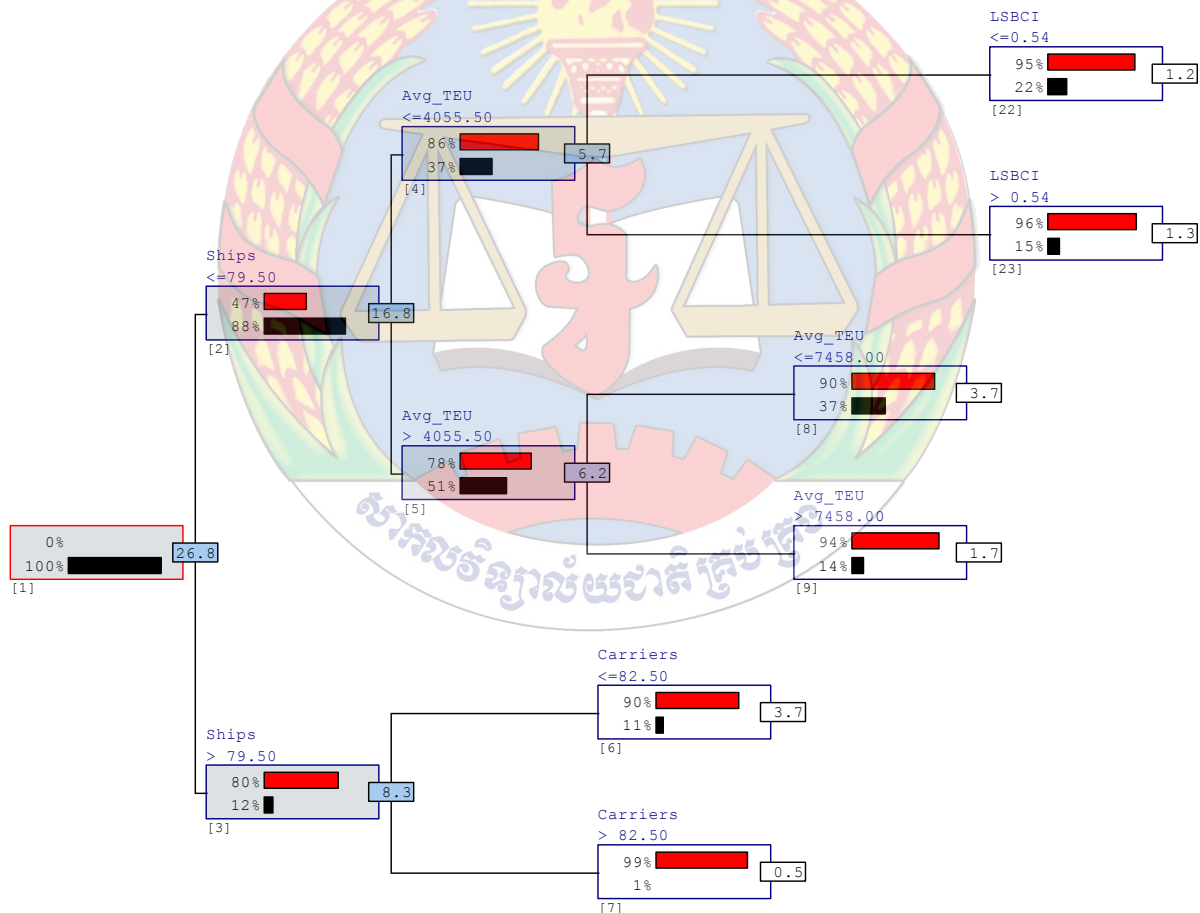
In summary, by applying the PCA approach, we have two components that summarize the seven key variables related to a sample of 3,054 maritime routes connecting 153 ports from 51 countries, including Hong Kong and Taiwan. These maritime routes can be characterized by two principal/basic components. The first one is related to the number of trips ships and carriers, while the second one refers to the ships per carrier, bilateral sea distance and the size of the ships. Based on these two components, we have conducted the Cluster Analysis and five clusters have been identified. The first one is characterized by its high level of competition and includes mainly intra-Asian routes. The second cluster includes long-distance routes, generally between Europe and America and America and Asia. On these routes there is a moderate level of competition. The third cluster has the highest level of market concentration (significantly higher than the other clusters) and most of the routes link Europe and Asia. The fourth and the fifth clusters are relatively similar

and situated on the first axes. However, the last cluster is the smallest one and includes the busiest intra-Asian routes.

4.4.4. Discussion of the typology and absolute concentration

An Interactive Decision Tree (IDT) based on the CART approach (Breiman et al., 1984) scrutinizes the typology by highlighting the most discriminating continuous variables. In this tree segments are created by successive division based on a given condition.

Figure 4.4: Interactive Decision Tree of the average size of vessels in TEU



Source: Authors' calculations

Legend: Above each box is written the name of the discriminatory variable as well as the value that divides a given segment. The number between the brackets below each box indicates the number of the segment. The number on the right side of each box indicates the part of the total inertia that is explained by dividing the segment. The Black bar refers to the group relative size (the percentage of maritime routes associated to this group). The red bar shows the homogeneity index (HI) which is estimated as follows: $HI = (1 - (\text{Inertia within Cluster} / \text{Total Inertia})) * 100$. The higher the value of HI is, the more consistent the cluster is (Coheris Analytics SPAD, 2018).

The first cutting is defined by the most discriminative variable. As we can see in Figure 4.4, in our case the number of ships appears to be such a variable. It divides the sample into two segments. All routes having more than 79.5 ships (12% of the sample) are associated with the first segment. These routes are also very homogenous (HI = 80%).

The second segment includes all routes with less than 79.5 ships (88% of the total sample). The index of homogeneity of the second segment is relatively low, 47%. Thus, it is necessary to further divide this segment. The second criterion to split up the sample is the size of the ships, below or above 4,055.50 TEU. The identified fourth and fifth segments are quite homogenous and represent 37% and 51% of the total sample size, respectively. As we can see, we are able to further divide the fourth segment, according to the Bilateral connectivity, while for the third segment, the cutting variable is the Number of carriers.

4.4.5. Competitive long distance routes (complementary analysis of a subset of 800 maritime routes)

PCA and Cluster Analysis are methods that are sensitive to outliers as well as the constitution of the sample. Considering the heterogeneous nature of routes and the fact that competitors will focus their efforts on larger sub-markets, thus increasing competition, we have decided to apply exactly the same approach as the previous section by including in the sample only the routes longer than 5,000 km. We have also removed from the sample those routes with fewer than 20 ships and 10 carriers. Finally, due to the presence of several outliers, routes with more than 1,000 trips were also removed. The final sample for the Principle Component Analysis consists of 800 maritime

routes. The results of this study are presented in Appendix 4.C. As active and supplementary elements, we have used the same variables as in the previous sections.

The PCA-based cluster Analysis has allowed us to identify 4 distinct clusters. The first one includes mainly transatlantic routes. These are the routes where competition is less intense (lower number of ships, trips, carriers than average), which can be explained by the low level of regional misbalance, which allows companies to operate efficiently and probably without having to share slot capacity with their competitors. The third cluster is similar to the first one and includes mainly routes between Asia and America. It is slightly more concentrated even though the distance and the average size of vessels are almost the same. On the other hand, the second cluster is made up mainly of routes between Europe and Asia. The absolute market concentration is higher in this cluster, 3.76 ships per carrier. The distance and size of vessels have the highest mean values among the clusters. The group with the lowest degree of competition is in the fourth cluster, which has the largest hub ports in the network and despite the lower mean values of distance and the size of the ships in comparison to the second cluster, the level of market concentration is the highest. These results suggest that the distance, frequency of services and the size of the ships do have an impact on the degree of competition. However, it is between major hub-routes that the highest frequency of services and at the same time the highest degree of monopolization are registered. This is confirmed by the interactive regression tree explaining the average size of vessels: the criterion of distance comes first to explain this variable, followed by the size of the company and the connectivity index.

4.5. Conclusions

The degree of competition on the maritime routes was evaluated through the simplest concentration ratios available in the Lloyd's List database, which are the number of ships per carrier and the average size of containerships deployed on the route. Unfortunately, unlike other studies focusing on a more limited number of routes, we did not have access to the distribution of market shares among liner companies for every route. Firstly, a descriptive statistics analysis of a sample of 6,410 routes between 153 ports reveals a regional misbalance between ports of origin

and destination, particularly between Asia and Europe, and Asia and America. The biggest vessels are deployed on these routes because of the long distance and the high degree of port connectivity with other ports, especially between Europe and Asia. These routes are also the most concentrated. The highest levels of competition measured by these simple instruments is observed on the intra-African routes, which can be characterized as the shortest distance between ports, smallest vessels, the lowest number of trips and the worst bilateral country connectivity. Furthermore, when we look at the origin and destination across regions, we conclude that the highest level of absolute concentration of the market is between Eastern Asia and Eastern Europe, South-East Asia and Eastern Europe, Southern Europe and Western Asia, and Western Europe and South-East Asia. It was found that competition is stiffer on the routes connecting mainly less developed regions such as Northern Africa and Eastern Asia.

Considering the heterogeneous nature of the whole sample we have decided to focus on the regular services (at least 12 trips on a route). We have also excluded all intra-country maritime connections. Therefore, the sample size was limited to 3,054 routes.

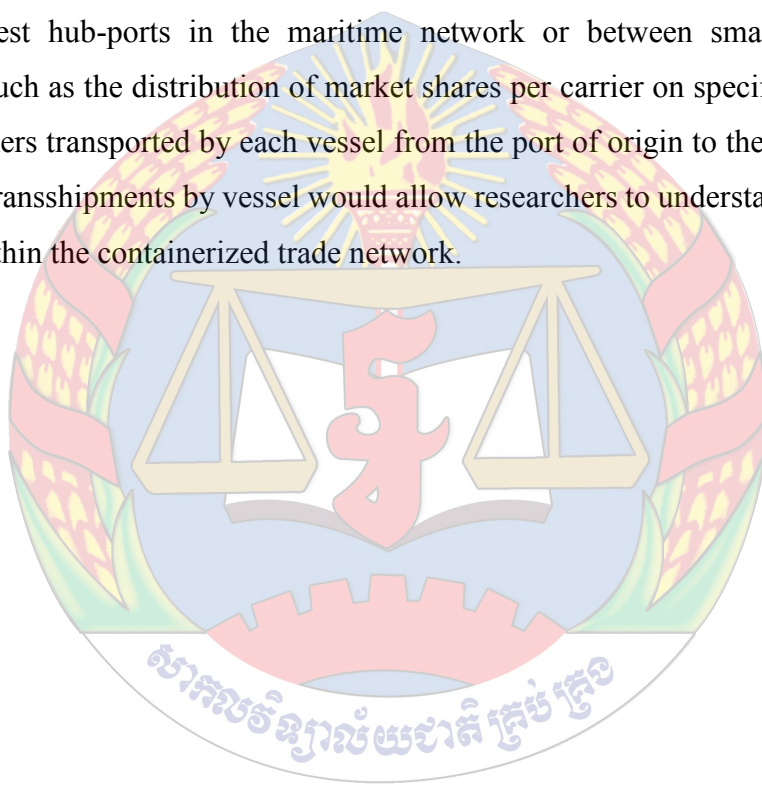
By applying Principle Component Analysis, we have identified two components which summarize the seven active variables and explain 70.4% of the variance. The first component relates mainly to the market size, frequency of services and competition (number of ships, trips, carriers), while the second illustrates a certain form of absolute concentration (ships per carrier) positively linked with the length of the route and the size of the ships. The two components are independent of one another.

The PCA-based cluster Analysis has allowed identifying five distinct clusters. The first and the third cluster are significantly different than the others. The former includes mainly intra-Asian routes and can be characterized by a high level of competition, while the latter is related to maritime routes between Europe and Asia where the absolute market concentration is the highest.

By conducting a similar analysis of a subset of 800 maritime routes (see Appendix 4.C) we have confirmed that large distance routes between connected ports are in general more concentrated in absolute terms (fewer companies operating larger vessels), exploiting the large-scale economies on these routes. However, the degree of competition varies across regions of origin and destination. The competition looks more intense on intra-African and intra-Asian routes

and also between less developed countries. The routes where the degree of competition is also relatively high are in intra-continental trade in Europe and America. On the other hand, the trade misbalance between Asia and America and Asia and Europe might be one of the main reasons for the relatively higher concentration on these routes. The PCA has shown that the Hub-and-Spoke network of the maritime transport leads to a smaller number of shipping companies operating a larger fleet of bigger vessels between the largest ports and these routes have the highest degree of concentration.

Additional studies should be conducted to analyze the nature of competition exclusively between the largest hub-ports in the maritime network or between smaller (feeder) ports. Additional data, such as the distribution of market shares per carrier on specific routes, the exact number of containers transported by each vessel from the port of origin to the destination as well as the amount of transshipments by vessel would allow researchers to understand better the nature of competition within the containerized trade network.



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4.7. Appendices

4.A. Regional container trade between the 153 ports in the sample.

	Mean TEU	Mean Ships	Mean Carriers	Mean Trips	Mean Distance	Mean Ships_per_carrier	Mean LSBCI
E.Asi-E.Eur	15377	15	3	62	14363	5	0.533
E.Eur-E.Asi	13423	9	3	21	21543	3	0.537
S-E.Asi-E.Eur	12166	7	1.67	31.33	13645	3	0.503
E.Eur-S-E.Asi	10889	10	2.33	30.33	13520	3.56	0.468
W.Eur-E.Asi	10003	26.08	6.94	55.86	19624	2.66	0.676
E.Asi-W.Eur	9867	32.33	8.07	79.29	18183	2.9	0.682
W.Eur-S-E.Asi	9524	48.71	10.65	135.1	15161	3.91	0.627
E.Asi-S.Eur	9173	24.12	6.75	57.12	14289	2.67	0.63
S-E.Asi-W.Eur	9036	56.34	12.31	172.28	15311	3.62	0.639
S-E.Asi-S.Eur	8900	36.82	11.57	101.61	11573	2.79	0.611
E.Asi-N.Afr	8897	28	8.5	58.62	13440	1.69	0.484
N.Afr-E.Asi	8714	35.37	8.76	68.57	15427	1.73	0.456
W.Eur-W.Asi	8669	30.08	9.36	63.19	9259	3.03	0.591
S.Eur-E.Asi	8337	15.96	5.65	31.91	16184	2.31	0.633
S-E.Asi-N.Afr	8146	52.07	13.27	132.07	11374	2.12	0.444
S.Ame-S-E.Asi	7820	30.88	12.88	93.25	17892	1.71	0.473
E.Asi-W.Asi	7806	14.16	6.69	24.82	9889	1.77	0.574
S.Ame-S.Afr	7736	51.5	27.5	152.5	8195	1.87	0.45
N.Afr-S.Ame	7643	30.5	14	138	10240	2.17	0.477
S.Eur-W.Asi	7642	25.12	7.24	67.12	6097	3.94	0.577
S.Eur-S-E.Asi	7584	29.29	9.18	82.07	11561	2.61	0.572
W.Asi-E.Asi	7500	17.37	6.7	26.19	10676	1.89	0.604
S-E.Asi-S.Ame	7368	31.11	12.33	114.44	18065	1.93	0.466
W.Eur-S.Asi	7281	18.42	7.74	48.68	11910	2.19	0.553
S.Ame-S.Asi	7186	8	4	12.67	15385	1.9	0.399
C.Ame-W.Asi	7172	1.33	1.33	1.67	19255	1	0.418
S.Afr-S.Ame	7081	30.5	17.5	94.5	8195	1.74	0.45
S.Ame-N.Afr	6845	15.75	7.25	86.25	12140	1.86	0.447
S.Asi-W.Eur	6665	18.71	7.79	45.54	12018	2.19	0.553
S.Afr-W.Eur	6656	12.43	5.29	59.57	12830	3.04	0.519

E.Asi-S.Ame	6637	34.17	14	87.57	16245	2.37	0.484
W.Eur-S.Afr	6637	14	6.29	58.86	12831	2.78	0.519
W.Asi-W.Eur	6611	14.68	5.9	34.45	9218	2.49	0.586
S.Ame-E.Asi	6609	20.62	9.08	43.5	18768	1.9	0.486
W.Asi-Carib	6575	6.5	4.5	8.5	15880	1.69	0.339
Carib-W.Asi	6509	8	4.5	8.5	15880	3.19	0.339
S.Ame-W.Eur	6288	18.9	9.29	89.48	10796	1.9	0.479
N.Afr-S-E.Asi	6220	44.86	10.95	124.95	11206	1.84	0.406
W.Asi-C.Ame	6218	2.4	1.6	2.6	18124	1.5	0.415
S.Eur-S.Asi	6119	8.59	3.35	27.65	8521	2.14	0.525
N.Ame-S-E.Asi	6066	11.3	4.14	29.02	13613	2.25	0.529
W.Eur-S.Ame	5997	15.8	8.04	74.44	10837	1.74	0.478
S.Asi-S.Eur	5996	10.83	4.54	33	8570	2.18	0.52
Carib-S.Asi	5936	5.5	2.5	5.75	17715	3.36	0.371
S-E.Asi-N.Ame	5887	12.8	4.92	35.18	13726	2.11	0.555
N.Afr-W.Asi	5847	34.58	11.89	80.58	5904	1.75	0.416
S.Ame-W.Asi	5803	1.5	1.5	2	15706	1	0.398
E.Asi-N.Ame	5701	28.36	11.72	83.95	8903	2.11	0.682
Carib-E.Asi	5666	11.31	6.92	22.46	17531	1.63	0.451
N.Ame-E.Asi	5648	27.22	11.21	79.14	10025	2.05	0.683
W.Asi-N.Ame	5600	11.09	5.91	24.75	16982	1.77	0.543
N.Ame-S.Asi	5580	10.67	4.63	23.25	17515	2.22	0.536
W.Asi-S-E.Asi	5564	28	10.19	41.89	6854	2.03	0.514
E.Asi-Carib	5532	17.33	10.08	48.17	14885	1.65	0.459
S-E.Asi-W.Asi	5470	29.36	12.64	43.5	6675	1.85	0.507
N.Afr-N.Ame	5437	10.47	5.42	21.78	10009	1.51	0.524
N.Afr-S.Asi	5418	23.67	10.33	52.56	7793	1.59	0.439
N.Ame-W.Asi	5234	12.26	5.8	28.49	16795	2.14	0.547
S.Eur-S.Ame	5205	10.47	5.16	74.26	10988	2.05	0.448
W.Asi-S.Eur	5185	20.89	8.49	55.94	5881	2.4	0.571
E.Asi-C.Ame	5145	52.09	21.47	127.74	13301	1.97	0.508
W.Asi-N.Afr	5129	21.5	9.94	58.39	5528	1.59	0.429
S.Asi-C.Ame	5122	1.2	1.2	1.2	19319	1	0.403
Carib-S-E.Asi	5117	4	1.4	4.8	19807	3.6	0.38
C.Ame-S.Asi	5060	1	1	1	18907	1	0.422
C.Ame-S.Afr	5059	1	1	1	13225	1	0.43
S.Eur-E.Eur	5046	6.8	2.8	21	3700	1.85	0.469
E.Eur-N.Afr	5027	11.75	7.88	43.63	4186	2.05	0.477
W.Eur-E.Afr	5026	13.14	3.29	38.71	7625	4.02	0.357

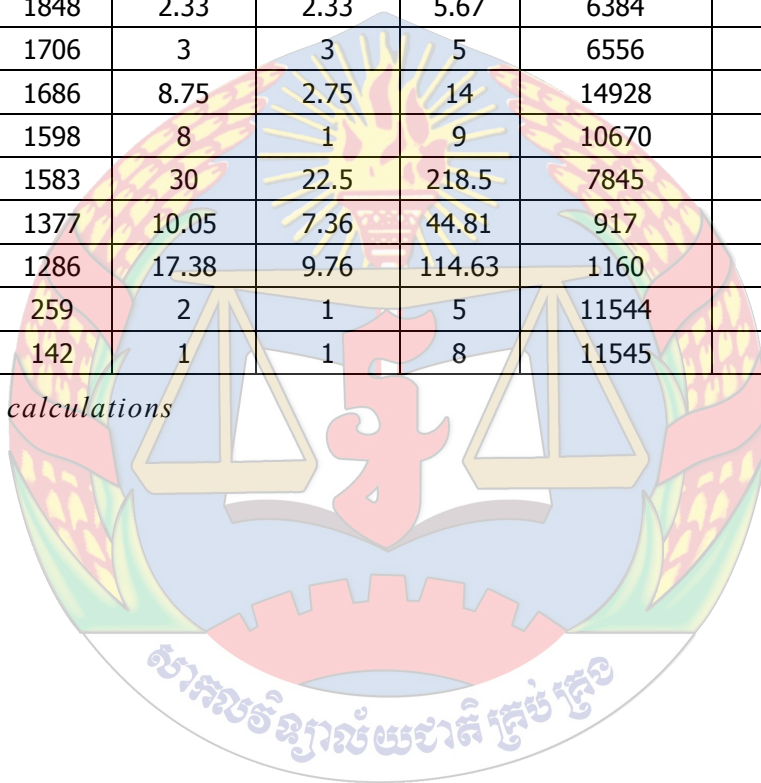
N.Afr-Carib	5007	1.33	1.33	1.33	8425	1	0.331
S.Asi-N.Afr	5001	15.17	7.25	34	8094	1.64	0.413
S.Eur-S.Afr	4984	6.71	3.29	31.71	11218	2.67	0.466
S-E.Asi-Carib	4967	5	1.75	6	20057	2.08	0.416
W.Eur-W.Eur	4900	127.2	49.12	777.82	1393	2.4	0.821
S.Afr-S.Eur	4899	7.14	4.57	34.71	11218	1.92	0.466
N.Ame-N.Afr	4868	14.47	6.37	30.81	9778	1.53	0.49
S.Ame-S.Eur	4848	9.1	4.05	60.9	10750	2.07	0.448
S.Asi-N.Ame	4813	11.72	6.06	28.17	17419	1.65	0.533
W.Eur-S.Eur	4810	25.43	11.22	102.94	2724	2.1	0.675
Carib-S.Eur	4804	12.25	6.75	22.08	7367	1.71	0.424
C.Ame-S-E.Asi	4782	7.78	5.22	9.89	17402	1.22	0.413
S.Afr-S.Asi	4766	24.5	10	48	6935	2.45	0.411
C.Ame-E.Asi	4747	39.82	17.85	89.76	14658	1.82	0.511
S.Asi-Carib	4672	3.25	2.25	4	17606	1.17	0.368
S.Eur-W.Eur	4666	22.4	10.5	102.76	2738	1.9	0.676
E.Afr-W.Eur	4658	6.25	2.5	12.63	7871	2.26	0.357
E.Afr-N.Ame	4630	4.33	3.33	12.33	15530	1.13	0.396
Carib-W.Eur	4628	12.25	7.17	45.67	6546	1.78	0.429
C.Ame-S.Ame	4616	39.25	17.67	157.25	7381	2.11	0.439
W.Eur-N.Ame	4597	19.53	8.73	68.81	8080	1.97	0.661
W.Asi-W.Asi	4553	58.91	24.09	211.45	2734	2.28	0.581
S.Asi-E.Asi	4544	8.76	5.27	19.15	8248	1.42	0.534
W.Eur-Carib	4496	14.38	7.69	52.08	6537	1.88	0.427
S-E.Asi-C.Ame	4475	9	5.89	12.78	17338	1.19	0.44
N.Ame-W.Eur	4461	18.46	7.93	63.26	7880	2.16	0.651
S.Eur-Carib	4450	9.27	5.67	19.07	7482	1.39	0.416
S.Ame-Carib	4440	16	8	53.13	6919	2.87	0.38
W.Eur-N.Afr	4428	31.42	12.16	89.82	2606	1.62	0.498
S.Eur-N.Ame	4421	15.32	6.8	46.87	8753	2.28	0.646
N.Ame-S.Eur	4395	13.31	6.04	40.2	8888	2.17	0.637
E.Eur-S.Eur	4392	3.57	2.43	5.14	3354	1.39	0.456
E.Asi-E.Afr	4388	10.2	5.47	38.6	9468	1.46	0.38
Carib-S.Ame	4379	16.25	8.13	52.25	6920	2.5	0.38
C.Ame-E.Afr	4375	1.5	1.5	2	16525	1	0.296
N.Afr-E.Afr	4289	20	7.67	52.33	4747	3.41	0.355
N.Ame-S.Ame	4264	14.47	8.91	54.95	8349	1.51	0.488
E.Afr-N.Afr	4249	15.33	8	34.67	4747	2.47	0.355
E.Afr-E.Asi	4225	11.13	5.2	33.6	10939	1.57	0.373

E.Asi-S.Asi	4206	6.73	3.71	14.63	7940	1.31	0.534
N.Ame-E.Afr	4204	10.25	7	30.25	15532	1.36	0.396
S.Afr-E.Asi	4194	29.31	14.81	59.5	13018	1.5	0.515
Carib-Carib	4150	22	7.5	53	1156	2.95	0.386
S.Ame-N.Ame	4136	14.36	8.9	54.67	7963	1.52	0.494
C.Ame-S.Eur	4101	15.52	7.84	50.84	9837	2.18	0.455
E.Asi-S.Afr	4054	34.69	17.31	72.69	12087	1.47	0.531
W.Afr-N.Ame	3987	1	1	1	9614	1	0.384
S.Ame-S.Ame	3970	54.5	24.1	253.3	6187	1.82	0.411
N.Ame-C.Ame	3968	22.95	11.8	79.36	2908	1.59	0.529
S.Eur-C.Ame	3958	14.63	7.44	49.59	9735	2.03	0.445
N.Ame-N.Ame	3944	24.3	10.7	91.86	253	1.85	0.622
Carib-C.Ame	3904	25.29	14.14	92.29	2941	1.79	0.381
S.Afr-S-E.Asi	3868	48.83	24.5	120.5	8944	1.45	0.459
N.Afr-C.Ame	3828	5.57	3.71	12.57	10155	1.28	0.373
Carib-N.Ame	3812	19.14	9.57	84.5	1889	1.95	0.517
S.Ame-C.Ame	3758	28.08	15.54	130.38	7408	1.41	0.417
W.Eur-C.Ame	3753	26.04	12.89	105.93	8778	1.64	0.466
S.Asi-S.Afr	3720	24	10	45.5	6935	2.52	0.411
S.Asi-W.Asi	3714	22.77	11.23	45.15	2793	1.79	0.536
E.Eur-S.Ame	3706	1	1	1	14481	1	0.39
S-E.Asi-W.Afr	3698	38.71	22.86	81.43	16030	1.64	0.403
C.Ame-Carib	3653	23.13	13.38	81.88	3217	1.77	0.38
N.Afr-W.Eur	3641	19.54	10.54	62.92	2687	1.46	0.503
S.Eur-S.Eur	3566	62.63	26.52	352.87	1162	2.18	0.62
N.Ame-Carib	3555	24.79	11.04	96.5	1868	2.27	0.509
W.Asi-S.Asi	3535	26.83	13	45.17	2739	1.52	0.539
W.Afr-E.Asi	3520	13.82	9.18	19.55	20247	1.46	0.425
E.Afr-S.Asi	3459	13.8	9.4	38.8	3781	1.56	0.37
C.Ame-N.Ame	3457	23.45	11.75	79.79	2882	1.53	0.534
C.Ame-W.Eur	3453	25.15	12.5	106.19	8543	1.65	0.461
E.Afr-S.Eur	3448	6.57	3.14	18.14	6101	2.53	0.372
Carib-N.Afr	3448	4.75	2.75	5.25	9102	1.4	0.346
Carib-E.Eur	3436	6	4.5	24.5	10816	1.19	0.373
E.Asi-W.Afr	3316	24.08	14.08	40.17	16809	1.48	0.421
E.Afr-S-E.Asi	3295	15.64	9.71	49.36	7491	1.37	0.349
N.Afr-E.Eur	3280	7.67	6.67	22.78	4118	1.16	0.429
S-E.Asi-E.Afr	3280	16.42	11.58	55.42	7343	1.33	0.35
S-E.Asi-S.Afr	3165	43.67	21	117.5	8944	1.53	0.459

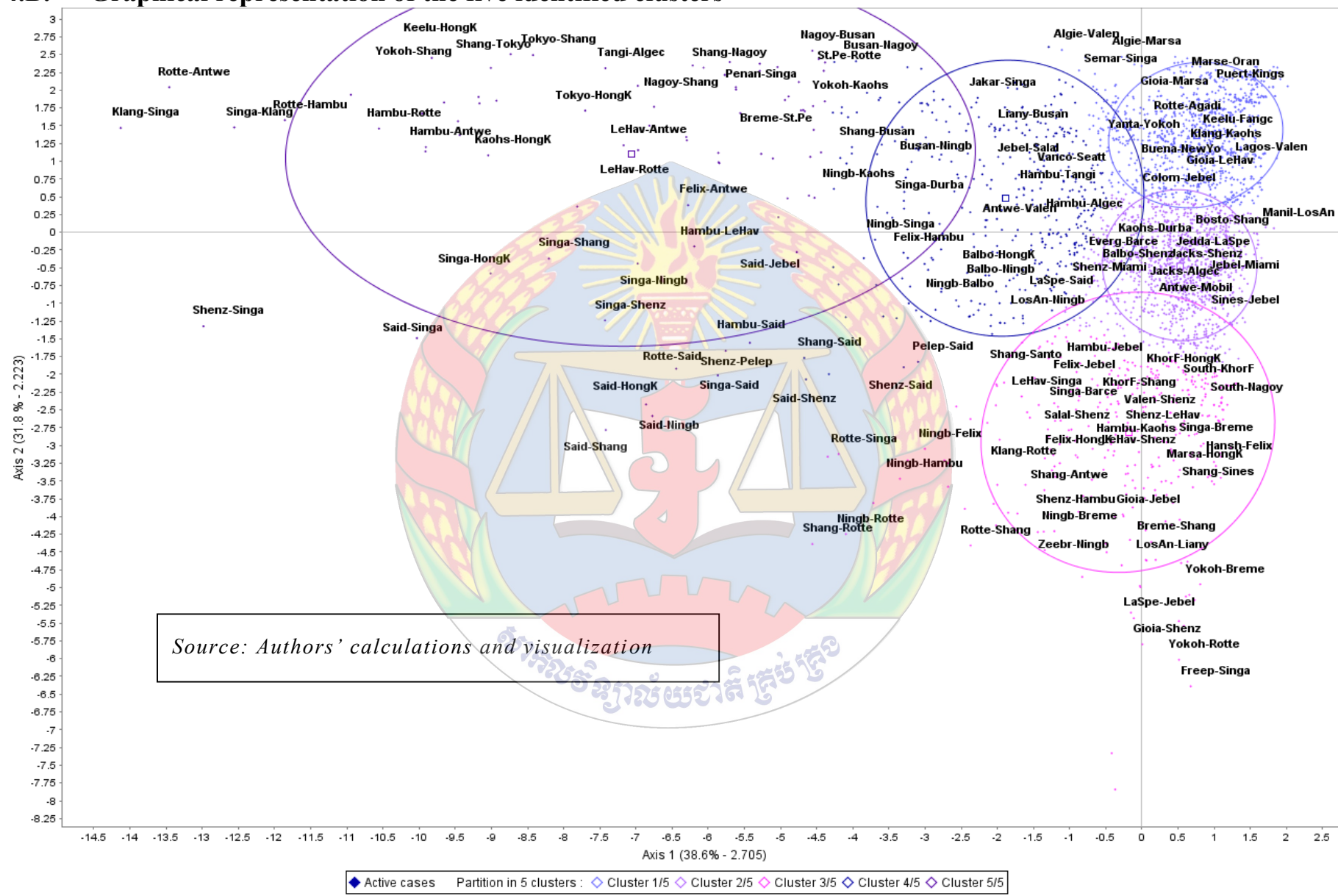
S.Afr-W.Asi	3161	29.25	16.75	74.5	7476	1.69	0.414
N.Ame-W.Afr	3128	1	1	1	10407	1	0.396
W.Afr-E.Eur	3113	15	5	30	8916	3	0.324
W.Asi-S.Afr	3112	28.25	16	76	7476	2.27	0.414
N.Afr-S.Afr	3060	2.67	1.67	5.67	10873	1.33	0.361
E.Afr-W.Asi	3040	30.29	16.14	115	3079	1.91	0.382
E.Eur-W.Afr	3035	9	2	14	8916	4.5	0.324
W.Afr-S-E.Asi	2952	19	12	34.15	16842	1.6	0.344
S-E.Asi-S.Asi	2792	18.41	10.97	43.15	4405	1.35	0.501
W.Afr-S.Afr	2776	26	16	39	6950	1.64	0.384
C.Ame-C.Ame	2767	28.2	14.1	108.7	2160	1.35	0.44
S.Asi-S-E.Asi	2764	14.21	8.82	32.42	4531	1.23	0.485
S.Afr-N.Ame	2764	8.29	4.14	33.14	14846	1.69	0.47
S.Asi-E.Afr	2761	16.25	9.5	45.5	3951	1.58	0.367
S.Eur-E.Afr	2757	5.36	2.64	18.09	5990	2.23	0.369
W.Asi-E.Afr	2738	24.38	12.5	99.87	3069	1.98	0.378
W.Afr-C.Ame	2732	1	1	1	8949	1	0.328
W.Eur-W.Afr	2724	11.77	8	43.38	7027	1.48	0.424
W.Afr-W.Afr	2695	58	37	126.5	819	1.51	0.422
S-E.Asi-E.Asi	2640	20.85	10.88	65.54	3923	1.43	0.554
C.Ame-N.Afr	2593	4.7	3.5	12.3	10348	1.24	0.37
C.Ame-E.Eur	2568	9.5	5.67	29.5	10656	1.59	0.351
Carib-S.Afr	2558	11	4	19	13353	2.75	0.359
W.Afr-W.Eur	2558	11.54	7.23	43.92	7046	1.49	0.42
E.Eur-C.Ame	2557	10.17	6.33	31.33	10656	1.53	0.351
E.Asi-S-E.Asi	2550	20.18	10.55	64.7	3592	1.39	0.551
S.Eur-W.Afr	2544	20.78	13.78	69	6258	1.36	0.421
E.Afr-E.Afr	2533	10	5	18.5	3223	2	0.316
W.Afr-S.Eur	2506	16.08	11.69	51.38	6146	1.22	0.425
S.Afr-E.Afr	2454	9.5	5.5	18.5	4925	1.68	0.343
S.Afr-Carib	2452	10	3	21	13354	3.33	0.359
E.Eur-Carib	2425	5.5	4	24.5	9514	1.21	0.348
W.Afr-S.Asi	2424	8.25	4.75	9.25	14311	3.12	0.365
S.Afr-W.Afr	2353	23	12	44	6949	1.89	0.384
E.Eur-W.Eur	2352	41.44	26.25	492.19	3802	1.41	0.476
W.Afr-N.Afr	2266	19.83	13.17	65.83	5885	1.55	0.407
S.Afr-N.Afr	2257	2.33	1.67	2.67	10701	1.67	0.428
E.Eur-N.Ame	2225	2.8	2	8.4	8409	1.57	0.518
E.Afr-S.Afr	2147	12.5	4	27.5	4925	3.08	0.343

N.Afr-W.Afr	2074	21.6	14.4	76.8	5418	1.59	0.379
N.Ame-E.Eur	2063	2.6	1.6	9	8410	1.7	0.518
N.Ame-S.Afr	2057	6.88	3.25	31	14869	1.7	0.472
S.Eur-N.Afr	2034	26.3	13.87	148.16	1005	1.47	0.441
E.Asi-E.Asi	1981	46.34	20.22	239.92	596	1.63	0.694
S.Asi-W.Afr	1969	10.5	4	15.5	14237	6.21	0.374
S.Asi-S.Asi	1946	8.5	5.65	19.5	722	1.16	0.561
W.Afr-W.Asi	1924	3.5	3.5	3.5	14930	1	0.365
N.Afr-S.Eur	1898	22.86	13.47	145.84	1036	1.4	0.432
W.Eur-E.Eur	1885	41	26.44	484.94	3960	1.32	0.476
S.Ame-W.Afr	1848	2.33	2.33	5.67	6384	1	0.328
W.Afr-S.Ame	1706	3	3	5	6556	1	0.331
W.Asi-W.Afr	1686	8.75	2.75	14	14928	6.46	0.365
E.Afr-W.Afr	1598	8	1	9	10670	8	0.273
E.Eur-E.Eur	1583	30	22.5	218.5	7845	1.33	0.338
N.Afr-N.Afr	1377	10.05	7.36	44.81	917	1.23	0.313
S-E.Asi-S-E.Asi	1286	17.38	9.76	114.63	1160	1.59	0.43
E.Eur-S.Afr	259	2	1	5	11544	2	0.403
S.Afr-E.Eur	142	1	1	8	11545	1	0.403

Source: Authors' calculations



4.B. Graphical representation of the five identified clusters



4.C. Results of PCA and Cluster Analysis relate to a sub-sample of 800 highly competitive routes (longer than 5,000 km, and more than 20 ships and 10 carriers operating).

Principle Component Analysis (PCA)

Considering the heterogeneous nature of routes and the fact that competitors will focus their efforts on larger sub-markets, thus increasing competition, we have decided to restrict our analysis on the routes longer than 5,000 km. In order to include the routes with regular services, we have also removed from the sample those with less than 20 ships and 10 carriers. Finally, due to the presence of several outliers, routes with more than 1,000 trips were also removed. The final sample for the Principle Component Analysis consists of 800 maritime routes.

As active variables included in the PCA, we use Avg_TEU, Ships, Carriers, Trips, Distance, Ships_per_carrier and LSB CI. The supplementary variables are the following: Route_Country, Route_Continents, Route_Regions and Trade_Direction.

First we present the correlation coefficients of the active continuous and discrete variables.

Pearson's correlations matrix for the subset of 800 maritime routes

	Avg_TEU	Ships	Carriers	Trips	Distance	Carrier_ships	LSB CI
Avg_TEU	1.000						
Ships	0.334	1.000					
Carriers	-0.079	0.789	1.000				
Trips	0.119	0.815	0.735	1.000			
Distance	0.481	0.141	-0.048	-0.043	1.000		
Ships_per_carrier	0.741	0.616	0.104	0.446	0.336	1.000	
LSB CI	0.475	0.282	0.037	0.152	0.180	0.480	1.000

Source: Authors' calculations and visualization

We observe similar Pearson coefficients as in the correlation matrix of the whole sample of 6,410 routes. However, the correlation between the variables ships and carriers is lower in this subset of data. In addition, the trips and ships seem to have a stronger positive relation. The correlation coefficient of Avg_TEU and Ships_per_carrier as well as Avg_TEU and Carriers_ships are higher than those related to the previous dataset. When we conduct the Principle Component Analysis, all variables are standardized.

First, we study the inertia of the principle components by analyzing the presence of correlation between variables and the components.

Explained variance by component in the PCA analysis

Axis	Variance of the axis (eigenvalue)	% of explained variance	Cumulated % of explained variance	Retained axes according to Kaiser's criterion
1	3.196	45.7	45.7	X
2	1.957	28.0	73.6	X
3	0.817	11.7	85.3	
4	0.555	7.9	93.2	
5	0.261	3.7	96.9	
6	0.167	2.4	99.3	
7	0.047	0.7	100.0	
Total	7.000	100.0	100.0	

Source: Authors' calculations and visualization

Following the Kaiser's criterion, we have decided to retain the first two components. Their cumulative percentage of explained variance is 73.6%.

Next we evaluate the contribution of variables to each of the two components. As shown in the average size of containerships, the distance between ports, ships per carrier and LSBCI have a significant and positive correlation with the first component and negative with the second one. On the other hand, the number of ships, carriers and trips correlate positively with both axes.

Correlation coefficients of active variables with the axis and the contribution of the active variables to the axis

	Correlations between active variables and factors		Contributions of the active variables to the axes (in %)	
	Axis 1	Axis 2	Axis 1	Axis 2
Avg_TEU	0.617	-0.665	11.9	22.6
Ships	0.910	0.336	25.9	5.8
Carriers	0.601	0.702	11.3	25.2
Trips	0.767	0.521	18.4	13.9
Distance	0.332	-0.558	3.5	15.9
Ships_per_carrier	0.812	-0.386	20.6	7.6
LSBCI	0.518	-0.420	8.4	9.0

Source: Authors' calculations

Note: In the upper-left corner: the factorial map of individuals; in the upper-right corner: representation of the active continuous variables; in the lower-left corner: representation of the supplementary categorical variables related to the Trade Direction and the Trade between continents; in the lower-right corner: representation of the supplementary categorical variables related to trade between regions.

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Active variables which have a major contribution to the construction of the first component are the number of ships and trips and, to a lesser extent, the average size of carriers. In other words, the most active routes are those where the traffic is intensive. Although linked to the first component, the weight of Distance is more limited compared to its influence on the second factor (negative correlation) where the number of carriers plays an opposite role (positive correlation). Therefore, the first component is related to the market size in terms of traffic and frequency of services, while the second component is associated with the increasing returns to scale of carriers facing long distance trade. Dropping the LSBCI variable and retaining the whole sample in the analysis, which is not presented here to avoid tedious presentation, these two dimensions appear even more clearly: the first component captures the number of ships, trips and ships per operator, while the second axis introduces the negative correlation between the distance (associated with the average size of ships) and the number of carriers. Long distance hauls commands the absolute concentration of the market, with fewer and larger operating carriers.

Looking at the illustrative variables related to the containerized trade between continents, we can see that within-Europe trade substantially contributes to the second axis. This route is situated in the upper-left corner of the graph, which means that smaller vessels and a higher number of carriers operate on the intra-European trade routes. Intra-African trade is opposed to the routes connecting Europe and Asia. At the regional level, we can clearly see that the outliers in the sample are the routes connecting Western Europe and Eastern Europe. In addition, on the second axis are opposed Eastern Europe-Western Europe and South Europe-Eastern Asia routes. The former has a shorter sea distance, smaller vessels and more carriers than the latter. On the first axis, we can distinguish several groups based on the regions of origin and arrival. The routes connecting South-East or East Asia and Northern Africa can be characterized as having more ships, trips and ships per carrier. On the other hand, routes between South Asia and South Africa, Caribbean and Central America, Caribbean and East-Asia, and South East Asia and Central America are perhaps more peripheral with a lower carrying capacity. Therefore, maritime routes have different characteristics and it seems useful to define different clusters based on the PCA active variables and described by both active and supplementary variables.

Cluster Analysis

As in previous section, we have used the same sample (800 maritime routes) to conduct the clustering analysis.

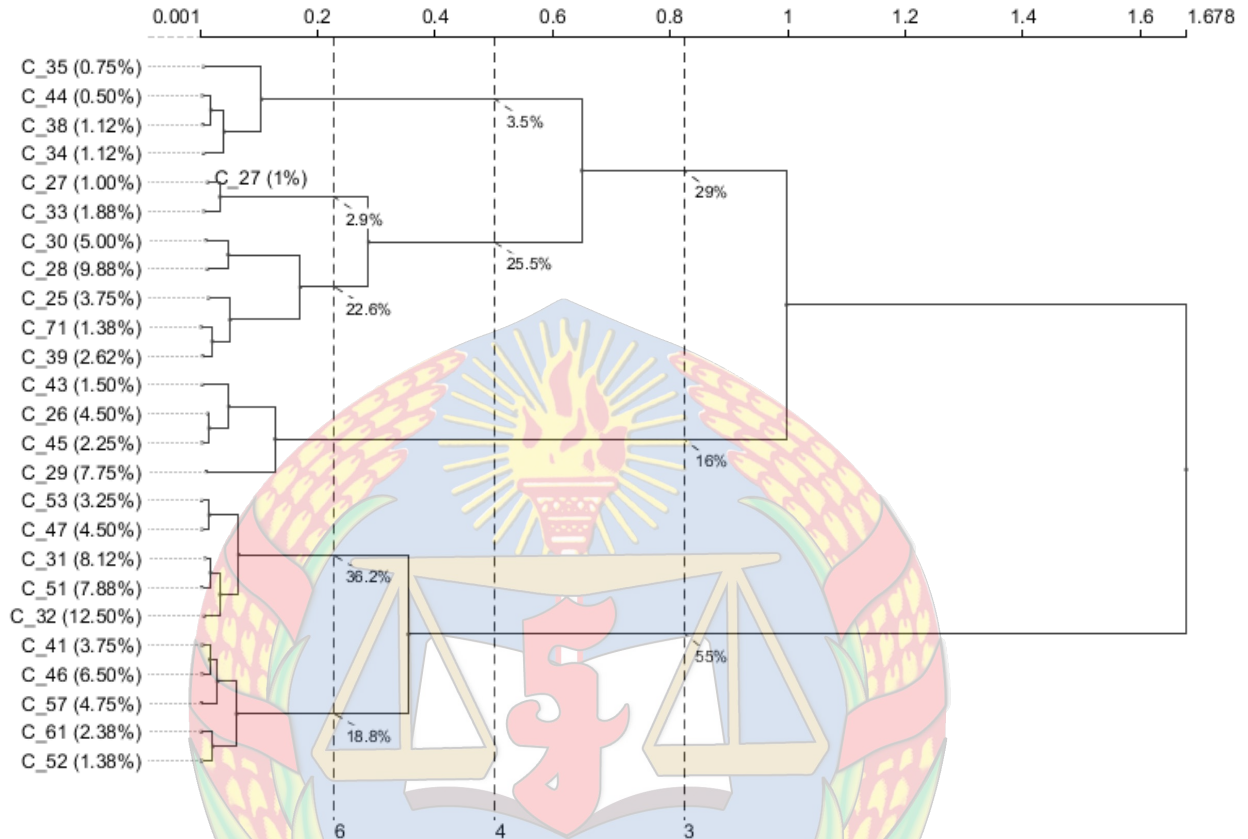
Indicators of the quality of the identified clusters following Agglomerative Hierarchical Clustering

Criteria	3 clusters	4 clusters	5 clusters	6 clusters
Intra-cluster inertia	2.476	1.827	1.473	1.186
Inter-cluster inertia	2.676	3.325	3.679	3.966
Explained inertia (%)	51.937	64.543	71.414	76.974
Calinski-Harabasz (pseudo F) criterion	430.626	482.984	496.521	530.849
Davies-Bouldin's index	0.988	0.903	0.829	0.831

Source: Authors' calculations

Even though, the Calinski-Harabasz criterion and Davies-Bouldin's index suggest that the optimum numbers of clusters are six and five respectively, it should be highlighted that the inertia loss by forming six clusters is very small, less than 10%. Therefore, we have decided to retain four clusters. The quality of the clusters is relatively good due to the low intra-cluster and the high inter-cluster inertia (or variance).

Dendrogram, Agglomerative Hierarchical Clustering based on the Ward criterion for the subset of 800 routes

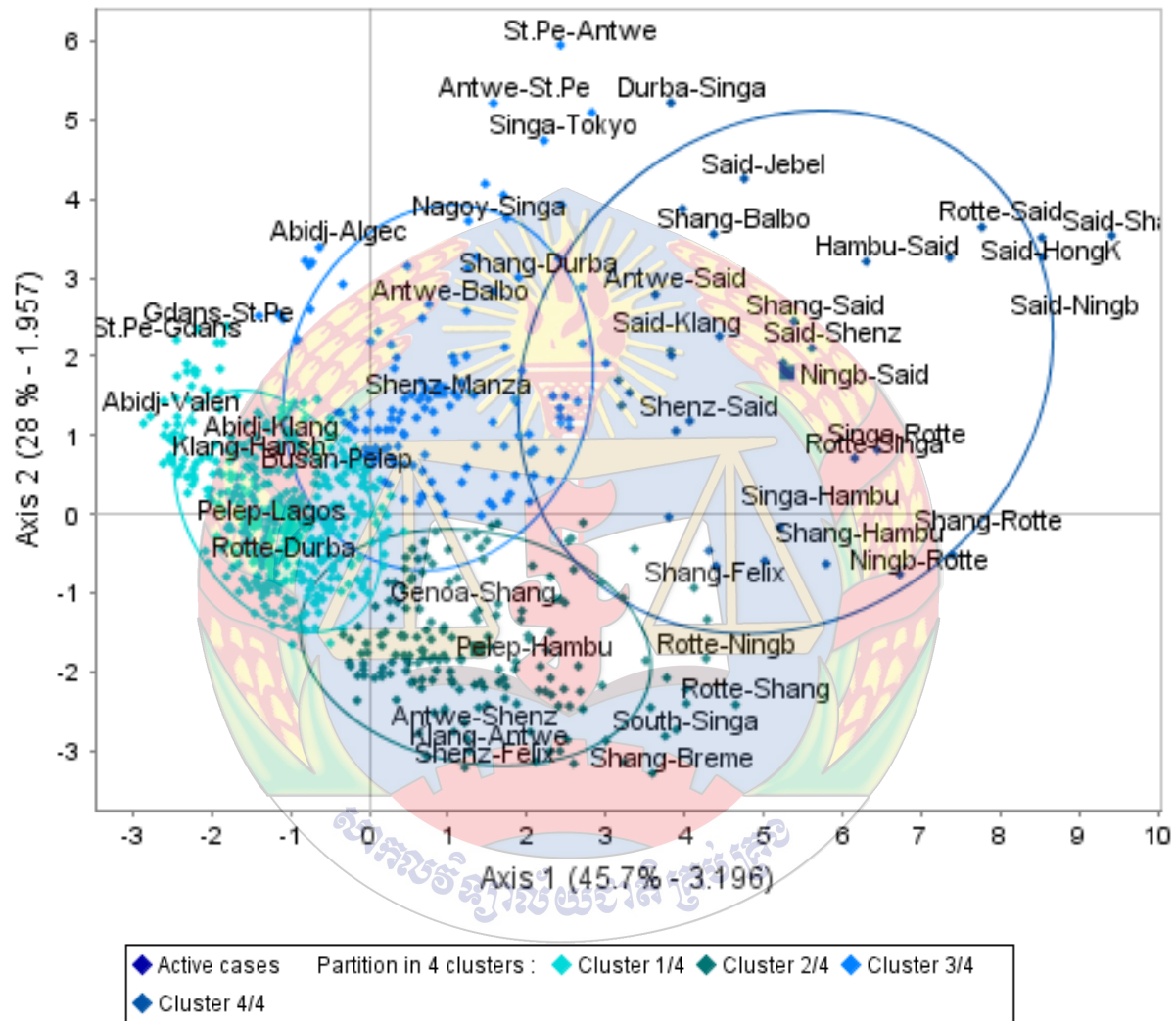


Source: Authors' calculations and visualization

By choosing to retain four clusters, we explain 64.5% of the total variability. These four clusters are depicted on the two axes that we have retained following the PCA (the Figure below). In the barycenter of cluster 1 is the maritime route connecting Tanjung Pelepas, Malaysia and Lagos, Nigeria. In 2014, between these two ports 36 ship with an average size of 4,293 TEU and 2.25 ships per carrier were operating. A typical representative of cluster two is the maritime connection between Tanjung Pelepas, Malaysia and Hamburg, Germany. There are 85 ships with a mean size of 9,850 TEU and 4.25 carriers per ship. Cluster three is represented by routes similar to the one between Shenzhen, China and Manzanillo, Mexico (89 ships, 6040 TEU and 2.07 ships per carrier). Finally, routes such as Ningbo-Zhoushan, China and Port Said, Egypt belong to the fourth

cluster. On this route, there are 251 ships with an average size of 9,232 TEU and 4.45 ships per carrier.

Graphical representation of the four clusters on the first two PCA axes



Some outliers and maritime routes close to the center of gravity of each cluster are shown as well. In order to have a better idea about the general characteristics of the four clusters, we provide the most significant statistics sorted out by a mean test for each one of them.

Cluster 1, transatlantic lines with low concentration (463 maritime routes)

The first cluster is the biggest one which includes 463 maritime routes. It is characterized by all seven active variables. Most of the routes in this cluster are between Developed (D) countries (37% of category in group) as well as between Developed and Less Developed (21.8%). The transatlantic routes are over-represented in this first cluster. All mean variables are slightly lower than the mean values for the whole sample of 800 routes, with the number of ships representing nearly half the sample mean.

Cluster 1 descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Test-value	Probability
Distance	10,548.800	11,354.700	3,781.090	4,172.200	-6.400	0.000
LSBCI	0.556	0.597	0.105	0.109	-12.463	0.000
Carriers	17.879	22.656	5.418	11.588	-13.659	0.000
Avg_TEU	5,381.440	6,529.610	1,602.970	2,552.900	-14.901	0.000
Trips	111.095	174.604	60.626	137.482	-15.305	0.000
Ships_per_carrier	2.109	2.619	0.442	0.994	-17.008	0.000
Ships	37.043	60.546	11.669	45.545	-17.097	0.000

Source: Authors' calculations

Cluster 1, descriptive statistics of the supplementary variables

Variable label	Characteristic categories	% of category in group	% of category in set	% of group in category	Probability
Trade_direction	D-D	37.1	33.6	63.9	0.008
Trade_direction	D-LD	21.8	25.6	49.3	0.003
Route_Continents	Eur-Ame	14.7	10.4	81.9	0.000
Route_Continents	Ame-Eur	11.0	7.9	81.0	0.000
Route-regions	S.Eur-N.Ame	5.6	3.5	92.9	0.000
Route_Continents	Ame-Ame	5.6	3.8	86.7	0.001

Source: Authors' calculations

The absolute concentration within this cluster is relatively low, with 2.1 carriers per ship on average, a vessel size below average and only 18 carriers against 23 per route in the selected sample.

Cluster 2, low degree of competition (170 maritime routes)

Some 170 maritime routes are included in the second cluster. All active variables except the number of trips are significant. This group is mainly linked with the second component. The routes are significantly longer (14,730 nautical miles) and characterized by fewer carriers operating nearly 4 ships on average and deploying rather large vessels (Avg_TEU is 10,149 TEU).

Cluster 2, descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Probability
Avg_TEU	10,148.800	6,529.610	1,468.070	2,552.900	0.000
Ships_per_carrier	3.764	2.619	0.946	0.994	0.000
LSBCI	0.687	0.597	0.058	0.109	0.000
Distance	14,729.900	11,354.700	3,821.480	4,172.200	0.000
Ships	69.624	60.546	26.788	45.545	0.002
Trips	170.953	174.604	80.117	137.482	0.348
Carriers	18.559	22.656	5.634	11.588	0.000

Source: Authors' calculations

Cluster 2, descriptive statistics of the supplementary variables

Variable label	Characteristic categories	% of category in group	% of category in set	% of group in category	Probability
Route_Continents	Eur-Asi	41.2	11.1	78.7	0.000
Trade_direction	D-L	35.3	25.6	29.3	0.001
Route_Continents	Asi-Eur	34.1	11.0	65.9	0.000
Route-regions	W.Eur-E.Asi	13.5	2.9	100.0	0.000
Route-regions	S.Eur-E.Asi	11.8	2.5	100.0	0.000
Route-regions	E.Asi-W.Eur	10.0	2.8	77.3	0.000
Route-regions	S-E.Asi-W.Eur	8.2	2.0	87.5	0.000
Route_Continents	Ame-Asi	6.5	14.8	9.3	0.000
Trade_direction	L-L	6.5	16.3	8.5	0.000

Source: Authors' calculations

From a regional perspective, this cluster gathers nearly all front and back hauls between Europe and Asia which represent three quarters of the cluster. The ports of departure or arrival for these lines have greater connectivity (nearly 10 points higher) than the rest of the sample. Absolute concentration of this sub-market is undoubtedly higher than previous cluster.

Cluster 3, high degree of competition (135 maritime routes)

There are 135 routes in the third cluster, mainly between Asia and America. The trade between China and the USA is substantial in this group. Unlike the second cluster, this group is mainly linked with the first component (market size). In this cluster, there are considerably more ships and trips than average. The variables which characterize the cluster are therefore Carriers, Trips and Ships. The average distance in this group is the shortest, with 9,549.44 km. On the other hand, competition on the routes is relatively intense between smaller carriers (2.46 ships per carrier, against 2.62 in the sample). The average size of vessels (around 5,300 TEU) is comparable to that of Cluster 1.

Cluster 3, descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Probability
Carriers	37.630	22.656	9.900	11.588	0.000
Trips	304.052	174.604	140.208	137.482	0.000
Ships	91.437	60.546	26.711	45.545	0.000
LSBCI	0.608	0.597	0.100	0.109	0.102
ships_per_carrier	2.464	2.619	0.513	0.994	0.023
Distance	9,549.440	11,354.700	3,245.700	4,172.200	0.000
Avg_TEU	5,336.050	6,529.610	1,530.720	2,552.900	0.000

Source: Authors' calculations

Cluster 3, descriptive statistics of the supplementary variables

Variable label	Characteristic categories	% of category in group	% of category in set	% of group in category	Probability
Route_Continents	Asi-Ame	20.7	14.1	24.8	0.013
Route_Continents	Ame-Asi	20.7	14.8	23.7	0.025
Route-regions	N.Ame-E.Asi	15.6	8.5	30.9	0.002
Route_Country	USA-CHN	11.1	3.8	50.0	0.000
Route_Country	CHN-USA	6.7	3.3	34.6	0.020
Route-regions	E.Asi-C.Ame	5.2	2.0	43.8	0.010

Source: Authors' calculations

Cluster 4, low degree of competition (32 maritime routes)

The last one is the smallest cluster, with only 32 maritime routes. This cluster is mainly linked with the first axis, like previous cluster, and the most significant variables describing it are also the number of ships, trips, and carriers. This cluster contains the trade lines operated either between developed or between less developed countries located mainly in Eastern Asia and Western Europe.

Cluster 4, descriptive statistics of the active variables

Characteristic variables	Category mean	Overall mean	Category Std. deviation	Overall Std. deviation	Probability
Ships	222.063	60.546	67.258	45.545	0.000
Trips	566.781	174.604	139.269	137.482	0.000
Carriers	50.375	22.656	14.711	11.588	0.000
Ships_per_carrier	4.581	2.619	1.161	0.994	0.000
Avg_TEU	8950.870	6529.610	1972.240	2552.900	0.000
LSBCI	0.666	0.597	0.064	0.109	0.000
Distance	12,701.600	11354.700	4563.120	4172.200	0.031

Source: Authors' calculations

Cluster 4, descriptive statistics of the supplementary variables

Variable label	Characteristic categories	% of category in group	% of category in set	% of group in category	Probability
Trade_direction	LD-LD	37.5	16.3	9.2	0.003
Route_Continents	Afr-Asi	25.0	5.8	17.4	0.000
Route-regions	E.Asi-W.Eur	15.6	2.8	22.7	0.001
Route_Continents	Asi-Afr	15.6	5.4	11.6	0.024
Trade_direction	D-D	12.5	33.6	1.5	0.006

Source: Authors' calculations

The degree of competition on the routes in the last cluster is the lowest: on average, there are 4.58 ships per carrier. Surprisingly, these are the busiest routes, the mean values of the number of ships and trips are considerably higher than average, 266% and 244% respectively. Most of the routes are between hub ports such as Port Said in Egypt situated near the Suez Canal, the Port of Singapore - the biggest port in ASEAN, the port of Rotterdam – the biggest port in Europe - as well as the port of Shanghai - biggest port in the world. This is confirmed by the higher connectivity degree (0.67), close to that observed in the second cluster. These direct connections between hub-ports seem to limit the degree of competition since they are dominated mainly by large companies operating large vessels.

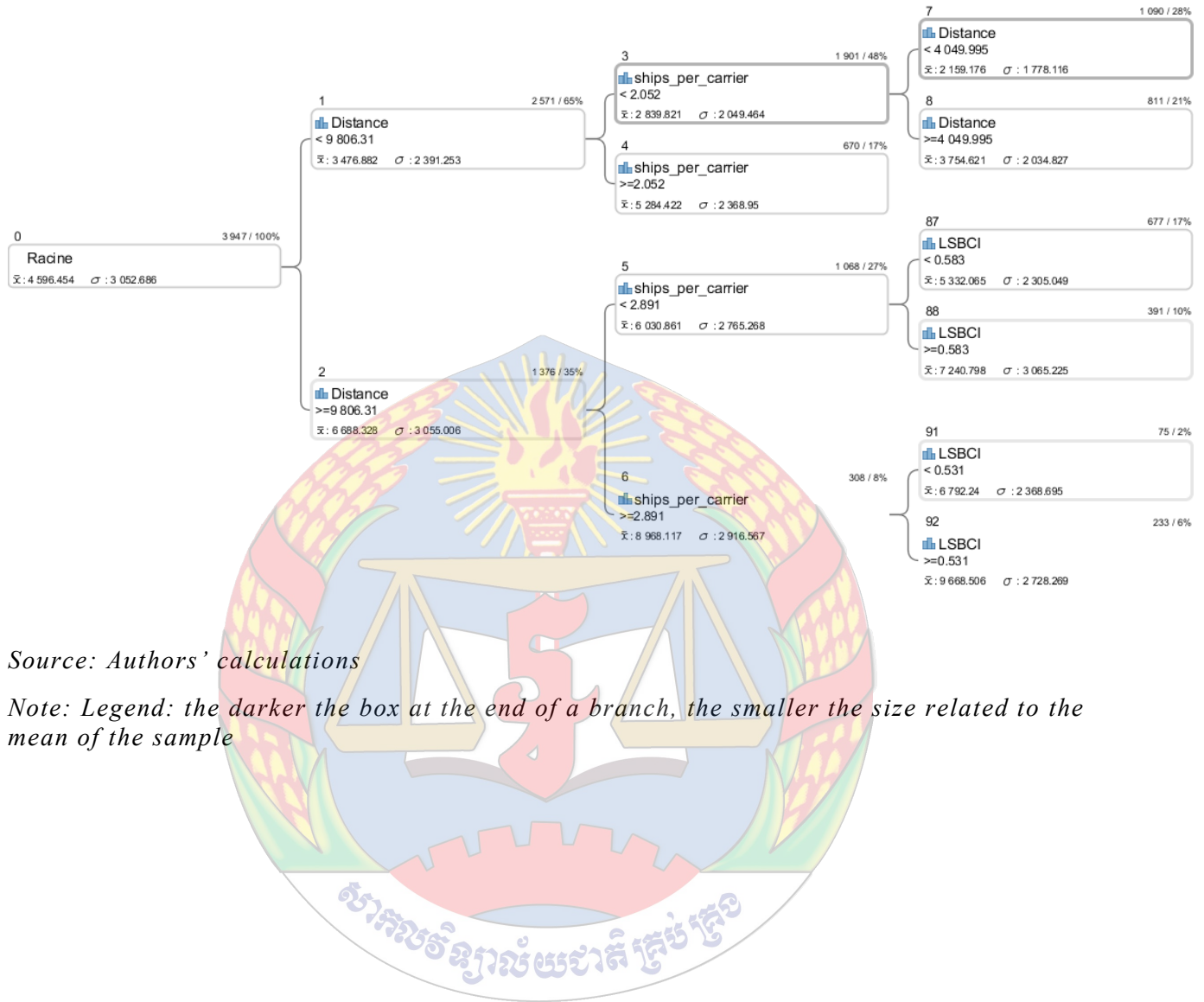
Discussion of the typology and absolute concentration

In summary, the cluster analysis allows us to identify four categories of maritime routes based on the active variables. We observe that the lowest degree of competition (4.58 ships per carriers) is within a small cluster of 32 very busy routes connecting large hub-ports. The second cluster is also constituted of routes with fewer large carriers connecting mainly Western Europe with Eastern and South-Eastern Asia. The degree of competition is the highest among the routes between developed countries (intra-American and Intra-European routes). The container flows on these routes are relatively symmetrical, which do not require a high degree of cooperation between carriers to optimize their costs (slot capacity). The degree of competition is also relatively high on the routes connecting America and Asia where substantial part of the trade is conducted between China and USA.

An Interactive Decision Tree (IDT) based on the CART approach (Breiman et al. 1984) scrutinizes the typology by highlighting the most discriminating continuous variables of the absolute concentration of maritime routes measured by the average size of vessels.

Starting with an average size of 4,596 TEU per ship (st.-dev. 3,053 TEU), the first criterion to split up the sample is the distance of the route in nautical miles, below or above 9,806 nautical miles. It is followed by the size of companies, the average number of ships per carrier. For shorter routes, the threshold is below or above 2.05 ships per carrier. For longer routes, this threshold is below or above 2.9. In other words, the companies owning less than 2.05 ships on routes shorter than 9,806 miles will operate the smallest containerships (2,839 TEU). By contrast, those carriers owning more than 2.9 ships on routes longer than 9,806 miles will operate large containerships of 8,968 TEU on average. The last discriminating criterion to increase further the average size of vessels is the connectivity of ports ($LSBCI > 0.53$): operating vessels between hub ports is likely to increase the size nearly up to 10,000 TEU.

Interactive Decision Tree of the average size of vessels in TEU



Source: Authors' calculations

Note: Legend: the darker the box at the end of a branch, the smaller the size related to the mean of the sample

Conclusion



The purpose of this research is to provide a comprehensive analysis of the structure of the Container Liner Shipping Industry at global and regional levels. Four chapters were dedicated to the following topics: the factors behind freight rates, the shipping networks, port efficiency and the level of competition on maritime routes. This conclusion is divided into three parts. First, a discussion on the main findings of the dissertation is provided. Secondly, a set of policy recommendations are listed. Finally, potential topics for future research are presented.

1. Discussion on the main findings

This dissertation has addressed four main research questions: What are the main determinants of container freight rates in, either, a steady growth of the industry or a crisis state? How is the container shipping network organized at both the world and ASEAN levels, and what is the role of different ports in this network? Which are the most efficient ports in ASEAN and what is their optimal container handling capacity? What is the level of competition on different maritime routes? To respond to the questions above, methodological tools such as Markov-Switching Vector Autoregressive Approach, Graph Theory, Data Envelopment Analysis, as well as Principle Component Analysis and Cluster Analysis were employed.

1.1. Results related to the factors behind freight rates and economic cycles in the Container Liner Shipping Industry

Chapter 1 investigated the relationship between the China Containerized Freight Index (CCFI), Containership Earnings, Fleet Development, the price of crude oil and Global Real Economic Activity for the period of 2003 to 2017. MS-VAR and IRF methods under the assumption of two regimes were applied to detect the structural breaks in the time series, and to analyze the causality between variables. The following major findings can be highlighted:

- **Existence of two very different and persistent regimes**

This study has found that the two identified regimes are very persistent. The first one is a regime of crisis, characterized by low and volatile freight rates, considerably low containership earnings and low global economic activity. The second regime depicts the uptrend in the industry, and can be illustrated by stable and high freight rates, significant containership earnings and increasing global economic activity. The switching probabilities for Regime 1 to move to Regime 2 and vice versa are very low, 18.5% and 17% respectively. This reveals that a crisis or a positive trend in the industry tends to last a very long time. Considering the asset intensive nature of the container shipping industry, analyses of the cyclical nature of the industry and the factors influencing freight rates are useful for a number of shipbuilders and container carriers who have to predict the evolution in the market in order to better plan long and medium-term investments. In addition, it should be noted that the demand for maritime transportation reacts quickly to the changes in shipment cost (Pantuso et al., 2014).

- **Three economic cycles have occurred between May 2003 and February 2017**

On the basis of the switching probabilities of the two regimes, three economic cycles have been identified throughout the observed period. The first cycle falls uniquely under the second regime and lasts 5 years and 4 months. This is a cycle of steady growth for the industry. It ends in the aftermath of the Subprime Mortgage crisis in August 2008. Indeed this finding is in line with the outcomes of the study of Stopford (2010) who stated that the longest and “most profitable” cycle in the international maritime trade occurred from 1995 to 2008 (13 years in total).

The second economic cycle spans from September 2008 to August 2014 (6 years). During this cycle, despite low switching probabilities, both regimes changed 10 times and on average every 7.2 months. This suggests that it was a transitional cycle marked by a rapidly changing shipping sector. It should be highlighted that there is a possibility that two or three sub cycles occurred. For instance, a study of Chistè and Van Vuuren (2014) gave evidence for the existence of a four-year cycle in the international seaborne trade.

Similar to the first cycle, the third cycle falls uniquely under one regime, Regime 1 (the crisis regime) and lasts from September 2014 to February 2017 (3 years and 4 months). It is a cycle of low and volatile freight rates, as both Alix Partners (2018) and UNCTAD (2017) stated in their reports. According to a number of organizations, the current state of the shipping industry is the

“New Normal” (Rex et al., 2017, ICS, 2018). Some structural changes in the world economy, the overcapacity in the industry, the containership upsizing and new technologies are the main reasons for this period of uncertainty and low growth of the international container trade.

Considering the fact that since September 2014 the industry has been operating entirely under the crisis regime, it should be expected that the “New Normal” state of the containerized trade might last at least three more years (until year 2021).

- **Fleet development has a substantial effect on container freight rates**

Impulse Response Function (IRF) reveals that the size of the world fleet has a substantial negative impact on freight rates. Its effect is more pronounced when the shipping market is in crisis (Regime 1) where a 1% increase in the size of the fleet leads to an immediate 3% decrease in container freight rates. In the case of the market uprising (Regime 2), a 1% increase in the fleet leads to an approximately 1.4% drop in freight rates. These outcomes are in line with the finding of Lun et al. (2013) of a strong negative relationship between freight rates and shipping capacity.

1.2. Results related to the Maritime Network at global and ASEAN+3 levels

Chapter 2 provided a comprehensive analysis of the global and ASEAN+3 maritime networks. Methods from the graph theory, such as centrality measures and modularity algorithms, were employed in the context of weighted directed networks. The outcomes of the study can be summarized as follows:

- **Hub-and-spoke structure of the global shipping network**

The high clustering coefficient (probability of being connected with other nodes in the network) and low density of the global shipping network at port level confirms the hub-and-spoke structure and scale-free configuration of containerized trade. Similar results regarding the structure of the global shipping network were obtained by Gastner and Ducruet (2015). In addition, UNCTAD (2017) also pointed out that in recent years the mainline services have increased, while direct connections have decreased. This means that there are a few very well connected ports

dominating the network. Smaller ports do not have many direct connections, and often the cargo must go through a major hub (transshipment port) in order to reach its final destination.

More precisely, major hubs were identified as the following ports: Singapore, Hong Kong, Ningbo-Zhoushan (China), Shanghai (China), Shenzhen (China), Port Klang (Malaysia), Rotterdam (Netherlands), Tanjung Pelepas (Malaysia), Kaohsiung (Taiwan) and Port Said (Egypt). In terms of closeness and betweenness degrees, these ports also have very high scores due to their numerous connections with other ports around the globe. As Ducruet (2013) pointed out, the most diversified ports have high levels of centrality and dominance in the network. These results are similar to the outcomes of the study of Wang and Cullinane (2016) who identified Shanghai, Hong Kong and Singapore as the most influential ports in the shipping network.

- **Geographical location of a port does matter**

The centrality measures allow researchers to have important insights regarding the roles of different ports in the network. For instance, even though in 2014 Port Said had an annual throughput of only 3.96 million TEUs, it had the highest closeness coefficient due to its unique geographical location. The port is located at the Suez Canal which connects the Mediterranean with the Red Sea, and is easily reachable by many other ports. Singapore is ranked second due to its role as a major hub connecting South-East Asia with Western Asia, Europe and Africa. The Chinese ports of Shanghai and Ningbo-Zhoushan located on the Yangtze River Delta, a large industrial and logistics area, have very high weighted closeness measures and rank 3rd and 5th respectively. Two other Chinese ports with strategic locations and high closeness centrality are Shenzhen and Hong Kong.

A high betweenness coefficient outlines which ports serve as important intermediate passages. Such ports are Singapore, Port Said and Shanghai. It is interesting to highlight that the port of Balboa is in 6th place. It is a hub connecting the Far East and North America with the West Coast of South America, Central America and the Caribbean. Similar to Port Said in Egypt, the Panamanian port has a strategic location on the Panama Canal which makes it a compulsory intermediate node for the majority of traffic in Latin and Central America.

The modularity analysis shows that different clusters of ports are formed regardless of their location. These results reveal that the geographical location of a port is not enough by itself to explain its connections with other ports.

- **Detecting important maritime countries in the global shipping network**

When the data is aggregated at a country level, results reveal that Japan, Egypt and Spain have very high closeness coefficients which means that they are easily reachable by the other states in the network. In terms of betweenness centrality, Spain, Japan, Germany and Malaysia are found to be the most important intermediate nodes connecting different clusters of ports. In terms of outdegree and indegree centralities, China, the U.S., Germany, Singapore and Netherlands are found to have the highest level of connectivity. Most of the container shipping traffic goes through these countries.

- **Detecting important ports connecting the ASEAN community to the global shipping network**

Unsurprisingly, the port of Singapore has the highest centrality measures in ASEAN. It is the gateway of ASEAN to the global supply chain. It is interesting that the port of Belawan (Indonesia), with an annual throughput of just 600,000 TEUs, is ranked 10th in terms of betweenness centrality. Obviously this port is not a hub, but is a compulsory passage for many smaller regional ports (feeder ports). Other ports such as Port Klang (Malaysia), Tanjung Priok (Indonesia) and Tanjung Perak-Surabaya (Indonesia) also play key roles in connecting the ASEAN community to the global shipping network. These findings should be considered in the context of the development of the ASEAN Single Shipping Market (ASSM).

- **Detecting the most important ports in ASEAN+3 community**

By looking at the ASEAN+3 network at a country level, the Japanese ports of Tokyo, Yokohama and Nagoya have the highest scores in terms of outdegree and indegree. This means that most of the traffic is concentrated at these ports. However, the most important intermediary passages were identified as the ports of Singapore, Shanghai and Hong Kong. The high closeness coefficient of Singapore confirms its role as a gateway port to the ASEAN Shipping Market.

- **High level of integration among ASEAN ports**

The modularity analysis shows that within the ASEAN+3 community, there is one cluster which includes 29 ports exclusively from ASEAN Member States. The only ASEAN country without any ports in this cluster is the Philippines. According to UNCTAD (2017), less than 20 percent of coastal country pairs have direct maritime connections between them. Therefore, the fact that a significant portion of ASEAN ports form one cluster suggests a considerable level of intra-ASEAN maritime integration.

- **Similarity between container traffic (trips multiplied by the average size of vessels) and the flows of exports (in US dollars) within ASEAN+3 community**

In a case study, two weighted directed networks of ASEAN+3 countries were compared. In the first network, the weight of the links between countries is according to the number of trips multiplied by the average size of vessels between the port of departure and destination. In the second network the edges are weighted by taking into account the value of export flows from one country to another. Results show that the major economies of China, Japan and Hong Kong, which act as bridges with Europe and North America, play a substantial role in both networks. It was also found that both networks have similar features. This suggests that the development of port infrastructure and connectivity is essential for a country's trade competitiveness.

1.3. Results related to the efficiency of ASEAN container ports and terminals

Chapter 3 focuses on the efficiency of ASEAN container ports by applying the benchmarking nonparametric method Data Envelopment Analysis (DEA). A sample of 49 ports was analyzed. In order to compare homogenous units, ports were classified into 6 categories according to their location (inland or seaport) and their container handling system in the container yard. The motivation for the research is the ongoing upsizing in the shipping industry which implies that larger containerships call at fewer ports, which results in a high level of congestion. In addition, handling requirements add pressure to berth and crane operations (UNCTAD, 2017). In the context of ASEAN container terminals and ports, the following results can be outlined:

- **ASEAN ports have good Scale Efficiency**

The first group includes 37 sea and inland container ports and terminals with yard cranes or SC⁷⁵s in the storage area. On average, the ports in the sample score well in terms of scale efficiency (0.802). In 2014, the ports in the first category had a total container throughput of 38 million TEUs. If they had operated efficiently under the CRS assumption (producing their CRS efficiency targets), they would have been able to increase the container throughput by 20.17% (7.7 million TEUs). On the other hand, if all ports were VRS efficient, they would have handled 10.83% additional containers (4.1 million TEUs).

Among the 29 sea and inland ports in the second category, using RTG and FT systems in container yards, eight were found to be efficient. Overall the average Scale efficiency was 0.798. In 2014, the total container throughput of these ports was 28.6 million TEUs. If all had been operating on the CRS efficiency frontier, they would have attracted 21.36% more of container volume (6.1 million additional TEUs). Regarding the efficiency under VRS, the total loss in terms of transported containers was 8.82%.

The third category includes 25 ASEAN sea container ports/terminals that operate yard gantry handling systems. Their average scale efficiency is 0.818. The ports in the sample handled 30 million TEUs in 2014. If they operated efficiently, they would have transported 4.7 million additional containers under CRS assumption, or 15.36% more. In the case of VRS efficiency, they would have increased their total throughput by 6.67% (around 2 million additional TEUs).

The fourth category consists of 22 ASEAN seaports/terminals that have RTG and FT handling systems in their container yards. The total container throughput of these ports in 2014 was 25 million TEUs. These ports also have a good scale efficiency of 0.814. If they had operated under constant or variable returns to scale, they would have been able to handle 29.6 or 27.7 million TEUs respectively.

In the last category all inland ports, which is 16 in total, have been included regardless of their handling equipment in the container yard. The total container throughput in 2014 for all ports in the sample was almost 8.8 million TEUs. If all of them were on the CRS efficiency frontier,

⁷⁵ SC refers to a Straddle Carrier system of handling containers

they would have increased their productivity by 20%. In terms of VRS efficiency, these ports would have been able to handle 18.68% more containers.

- **Cluster Analysis and DEA could be complementary methods**

In order to verify the outcomes of the DEA methodology, a Cluster Analysis based on a prior Principle Component Analysis was applied. As active variables were used simple productivity ratios, the annual container throughput divided by the input variables (max depth at berth, size of the container yard, length of the quays, number of quay cranes, number of yard cranes (MRGC, SC or RTGC), number of forklifts and number of trucks). The DEA results were found to be consistent and as expected, efficient ports form separate clusters. In addition, Cluster Analysis highlights potential benchmarks for inefficient ports. Indeed, the study has demonstrated that DEA and Cluster Analysis are complementary methods.

- **Under the assumption of CRS, between 24% and 30% of ports are efficient**

Overall, in terms of technical efficiency (the amount of output that a port is able to produce with its inputs), it is observed that in the first and second categories 24% and 28% of ports are CRS efficient. In the third and fourth categories the shares of CRS efficient ports are 30% and 27% respectively. These results are similar to study of Hung et al. (2010) who found that 26% of Asian container ports are regarded as CRS efficient.

- **Under the assumption of VRS, between 44% and 50% are found to be efficient.**

When we look at the efficiency of ports under VRS assumption, in the first category 49% of the ports are found to be efficient, while in the second, third and fourth categories the share of VRS efficient ports is 44%, 54% and 50% respectively. These are similar outcomes to the study of Bichou (2013) which concluded that most container terminals are VRS efficient.

- **The source of inefficiency is the small size of ASEAN ports**

In all categories, most of the ports operate under increasing returns to scale which means that these ports should increase their inputs in order to become more efficient. Very few are experiencing decreasing returns to scale. Thus, with respect to the DEA models applied in this study, it can be concluded that the reason for the inefficiency of most ASEAN ports is their small

size. It should be highlighted that a similar study of Dan et al. (2013) focused on Chinese ports and found 35% input excess in coastal container terminals.

However, the large size of some ports has a negative effect on their productivity. Cullinane and Wang (2006) pointed out that large ports are associated with decreasing returns while small ports generally operate under increasing returns to scale. In line with their findings, this study has found that the North Port Container Terminal-Port Klang (3.5 million TEU annual throughput), Hải Phòng Port (1 million TEU annual throughput), Saigon New Port (4 million TEU annual throughput) and Belawan International Container Terminal (almost 900,000 TEU annual throughput) operate under decreasing returns to scale. Ports such as TLT-HLT⁷⁶, Manilla International Container Terminal, Bangkok Port, Terminal Petikemas Surabaya, and other ports with annual container throughput greater than 1 million TEUs operate under increasing returns to scale. These findings suggest that a number of relatively big ASEAN ports have the potential to further increase their container handling capacity.

1.4. Results related to competition on maritime routes

Chapter 4 focused on the level of competition on maritime routes. A key variable in the study is the average number of ships per operator between a port of arrival and destination (maritime route). Additional continuous and discrete variables were also used in the study such as number of trips, number of ships, number of operators, average size of vessels, Liner Shipping Bilateral Connectivity Index and sea distance. Qualitative variables such as continents, regions and trade direction for each maritime route were also included. By applying Principle Component Analysis and Cluster Analysis, some interesting empirical results regarding the structure of the containerized trade have been revealed:

⁷⁶ Thai Laemchabang Terminal Co., Ltd. and Hutchison Laemchabang Terminal Limited

- **Higher level of concentration on maritime routes between developed countries**

Descriptive statistics have shown that the market concentration is the highest on routes connecting developed countries⁷⁷. On these routes the bilateral connectivity is the highest, and the number of ships, trips and operators, and the size of the boats have the highest mean values.

- **Market concentration is the lowest between less developed countries**

On the routes connecting less developed countries the lowest level of competition was recorded with only 1.51 ships per carrier. These routes are mainly between countries with an average distance of 2,884 nautical miles.

- **Slight imbalance in containership traffic between developed and less-developed regions**

The study has shown that there are slightly more trips from less developed countries to developed ones than the opposite direction. In terms of market concentration on maritime routes, both directions have almost the same results with around 1.80 ships per carrier.

- **Highest level of market concentration on the routes connecting Europe and Asia**

On the routes Europe-Asia and Asia-Europe the highest levels of market concentration, 2.80 and 2.76 ships per carrier respectively, were recorded. It is important to detect such routes because, as UNCTAD (2017) pointed out, the growing concentration of the market has increased the risk that fair competition may become distorted and result in an oligopolistic market structure being significantly busier than the average.

- **Maritime routes can be classified based on two components: market size and economies of scale**

Following the Principle Component Analysis (PCA), two components have been retained. The first one is related to the market size in terms of traffic and frequency of services, while the second component is associated with the increasing returns to scale of a small number of carriers facing long distance trade.

⁷⁷ A develop country is a state classified by the World Bank as high income country. This study consider as less developed countries, all countries belonging to the other categories of the World Bank.

- **Categorization of maritime routes**

Based on these two components, we have conducted the Cluster Analysis and five clusters have been identified. The first one is characterized by its high level of competition and includes mainly intra-Asian routes. The second cluster includes long-distance routes, generally between Europe–America and America–Asia. On these routes there is a moderate level of competition. The third cluster has the highest level of market concentration (significantly higher than the other clusters) and most of the routes link Europe and Asia. The fourth and the fifth clusters are relatively similar and situated on the first axes. The last cluster is the smallest one and includes the busiest intra-Asian routes.

- **The routes connecting major hub ports recorded the highest levels of market concentration and frequencies of service**

PCA and Cluster Analysis on a subset of 800 long-distance maritime routes revealed that the highest levels of market concentration (ships per carrier) are observed on the routes connecting major hub ports. Therefore, the same conclusion as the second chapter could be made that the network is dominated by a relatively small number of large hub ports. In addition, on these routes, the competition between container carriers is the lowest.

2. Recommendations

Chapter 1 shows that since September 2014 the container liner shipping industry has entered a cycle of low growth and high level of uncertainty. Previous research has found that on average a cycle in the shipping industry lasts seven years. However, the current cycle might even last longer due to the recent comeback of protectionist policies, slow growth of the Chinese economy, and changing demographics in developing countries. To make things worse, the current free-trade based system might become obsolete since “the WTO was supposed to contain trade disputes and prevent retaliatory pile-ups. Today it appears to be a horrified bystander as the system it oversees crumbles.”⁷⁸ These trends in international trade are having substantial impacts on containerized trade.

⁷⁸ <https://www.economist.com/leaders/2018/07/19/how-to-rescue-the-wto>

Based on the findings of this research, a set of policy recommendations at global and regional levels are made by taking into account some of the issues and challenges facing the industry. These recommendations aim to make the container shipping more sustainable.

2.1. Addressing the overcapacity in the industry

In the first chapter it was clearly demonstrated that the development of a containership fleet has negative impacts on freight rates, especially in the regimes of crisis. The container segment is oversupplied, so the industry does not manage to regulate the capacity (Danish Maritime Forum, 2016, ICS, 2018, Rex et al., 2017). In order to prevent any further bankruptcies of major companies like Hanjin Shipping, it is important to try to find a sustainable solution to this issue.

The IMO, by collaborating with different stakeholders such as IACS, ICS, ILO and WSC, should impose further environmental and safety regulations on shipping such as those related to the amount of sulphur in fuel, Ballast Water Management, improvements in energy efficiency of ship engine oil, reduction in the quantity of spilled oil, reduction of ships' CO2 emissions, port State Control and others. A set of amendments to the existing international conventions, such as SOLAS, MARPOL and LOADLINE, should be adopted. This eventually will increase the scrapping of containership vessels uncompliant with the regulations. In addition, on behalf of the industry, the ICS has expressed a commitment to reduce the total CO2 emissions by 50% by 2050. However, it should be noted that most of the uncompliant vessels are less than 6,000 TEUs and deployed mainly on North-South and intra-regional trades. “Nothing is done to alleviate the pressure on East-West routes, where virtually all of the new build capacity is placed.”⁷⁹

Reducing ship speed is another solution to alleviate overcapacity. This allows companies to not only reduce fuel cost but also reduce the number of idle ships. Psaraftis (2016) stated that the slow steaming practices are a “win-win” solution. Moreover, a study of Faber et al. (2017) estimated that by reducing the speed of all vessels by 8%, the carbon footprint of the containership industry would decrease by 12%.

⁷⁹ https://www.porttechnology.org/news/drewry_scrapping_not_overcapacity_solution

Reintroduction of cancellation fees is among the primary market approaches to reducing the overcapacity in the industry. It will avoid the over-booking of ships per carrier in anticipation of “no shows”. Since May 2017, such a strategy (150 USD cancellation fee) has been applied by CMA-CGM for the following destinations: Far East, South East Asia and the Indian Sub-Continent⁸⁰. Maersk Line also applies a similar approach to all shipments with origin from China. In May 2018, the company increased the cancellation fees to 200 USD per 40’ container and 100 USD per 20’ container⁸¹.

Investment in port infrastructure, ensuring economic growth in emerging countries and promoting intra-regional trade, is a policy that will increase the demand for capacity in the container segment. According to the statistics of the World Bank, since 2008, the private participation in ports’ infrastructural projects has been more than 37.7 billion USD. The regions where most of the funds have been invested are Latin America and the Caribbean at 18 billion USD, and Sub-Saharan Africa at 9.2 billion USD⁸². More than 50% of these projects are Greenfield projects⁸³. Important investments have been made in Nigeria, Brazil and South Africa. In addition, in order to ensure sustainable growth in the logistics sector in developing countries, some protectionist policies are needed, such as in Nigeria where it could also lead to a further increase in intra-regional trade in West Africa and elsewhere (Danish Maritime Forum, 2016).

2.2. Promote ASEAN maritime integration

The vision of ASEAN Connectivity 2025 is to achieve a “seamlessly and comprehensively connected and integrated ASEAN that will promote competitiveness, inclusiveness, and a greater sense of Community” (ASEAN, 2016b). Important components of the strengthening of ASEAN competitiveness and the fostering of regional inclusive growth are the improvement of transport

⁸⁰ <https://www.cma-cgm.com/local/united-kingdom/news/198/cancellation-fee-new-in-may-2017>

⁸¹ <https://www.maerskline.com/news/2018/05/11/cancellation-fee>

⁸² <https://ppi.worldbank.org/snapshots/sector/ports>

⁸³ <http://ppi.worldbank.org/methodology/glossary> : “A private entity or a public-private joint venture builds and operates a new facility for the period specified in the project contract.”

cooperation through greater connectivity, efficiency, integration, safety and the sustainability of ASEAN maritime transport (ASEAN, 2015a).

Additional efforts and investments to improve the ports' intra-regional connectivity would increase ASEAN competitiveness. As Chapter 2 has demonstrated, the structure of the Trade and Maritime Networks of ASEAN+3 Member States have similar features. Both networks are dominated by China, Japan and Hong Kong. Therefore, some ASEAN Member States such as the Philippines, Cambodia, Vietnam and Indonesia should invest more resources in increasing their level of connectivity. The study has also shown that all ASEAN Member States except the Philippines form a cluster of well-interconnected ports. Therefore, a potential increase in the number of maritime connections of the Philippines, with ASEAN ports, is needed. It will eventually improve the inclusiveness and the intra-regional ASEAN trade.

Improvement of data availability and information regarding ASEAN port infrastructure and investments would help to foster intra-regional trade. Indeed, key priorities and challenges for ASEAN are the financial access through digital technologies, improvement of open data use, and enhancement of data management in ASEAN Members States (ASEAN, 2016b). As has already been discussed, it is a challenge to have access to information regarding port connectivity and infrastructure. Furthermore, it was found that some sources of secondary data, such as “Guide to Port Entry⁸⁴”, have outdated information for ASEAN ports. Regarding data obtained from Lloyds Maritime Intelligence, the coverage is very limited for some small ports like Phnom Penh Autonomous Port. Making data available would improve the decision-making process, and future policies would be based on up-to-date reliable information.

Improvement of trade and maritime integration could be possible by limiting trade barriers and reducing the administrative burden for logistic companies in all ASEAN Member States. According to the Liner Shipping Connectivity Index (LSCI) computed by the World Bank, the connectivity of the ASEAN community to the global shipping network has improved significantly in the last decade. From 2005 to 2016, LSCI increased by 65.06% with an average annual growth rate of 4.30%. However, disparities across ASEAN Member States are considerable. According to the rankings of the Trading Across Borders Index, Singapore is in

⁸⁴ <https://www.portinfo.co.uk/products/product/115-guide-to-port-entry-2017-2018>

second place, while Myanmar is in 174th place⁸⁵. As of 2018, export documentary compliance takes an average of 2 hours in Singapore and 132 hours in Cambodia. A recent report from Transparency International has highlighted that tariffs for some requested services by customs (administration fees, facilitation fees and other charges) are not announced. In these cases, a local company must be hired to transport the shipment and pay the informal payments (Areias et al., 2017). In addition, border compliance is the least time consuming in Singapore (10 hours) and the most time consuming in Myanmar (142 hours). It is necessary to adopt similar procedures in all ASEAN Member States because research shows that countries having the highest scores in terms of port connectivity also have the lowest levels of red tape and the fastest customs clearance processes.

Enhance the maritime integration of ASEAN through detecting ports where the risk of congestion is the highest. The improvement of supply chain efficiency by key chokepoints is among the main priorities of the Master Plan on ASEAN Connectivity 2025 (ASEAN, 2016b). Graph Theory allows policy makers to identify the ports where most of the traffic is concentrated. For instance, this dissertation has highlighted that the most important countries in the ASEAN maritime network are Singapore, Malaysia and Thailand. More precisely, the highest hub coefficients belong to the ports of Singapore, Port Klang (Malaysia), Tanjung Pelepas (Malaysia) and Laem Chabang (Thailand). These ports are crucial for connecting ASEAN with the global supply chain. ASEAN Member States should have a plan for diversifying the traffic to other ports, in case of human-made or natural disasters in these ports.

2.3. Improve the operational performance of ASEAN ports

Along with the upsizing of containerships, the improvement of the efficiency of operations at ports has become a challenge. ASEAN Member States have expressed a commitment to enhance the region's participation in the global value chain through "better realization of economies of

⁸⁵ <http://www.doingbusiness.org/data/exploretopics/trading-across-borders>

scale, collective efficiency and the organic formation of regional innovation systems” (ASEAN, 2015a).

Improvement of infrastructure and enlargement of existing container ports in almost all ASEAN Member States is necessary to increase the integration of the community into the global supply chain. Chapter 3 has stressed that ASEAN ports have relatively good scale efficiency, although almost all of them operate under increasing returns to scale. This means that further investments in the enlargement of existing ports could be undertaken in order to boost the ASEAN container throughput capacity.

Improvement of the ports’ management is a necessary step to foster trade competitiveness for the ASEAN region. This dissertation has demonstrated that less than 50% of the ASEAN ports are efficient under the assumption of Variable Returns to Scale. When a port is VRS efficient but not CRS efficient it means that there is a lack of productivity related to the size of the port. As we have seen, the source of inefficiency for the large majority of ASEAN ports is their small size. Therefore, it is important to make available to the ports’ authorities the good practices in terms of transport facilitation, in order to establish efficient and globally competitive logistics and multimodal transportation systems for the seamless movement of cargo within and beyond ASEAN (ASEAN, 2015a). The coordination between the ASEAN ports and their harmonization of standards and systems is also necessary.

Potential reduction of the capacity of some ASEAN ports could be considered. The DEA analysis has shown that North Port Container Terminal-Port Klang, Hải Phòng Port, Saigon New Port, and Belawan International Container Terminal operate under decreasing returns to scale. This implies that their size is a constraint to their optimal productivity. Considering the sensibility of DEA to outliers, it is necessary to double check the findings in Chapter 3 by conducting an assessment of the infrastructure of these terminals/ports and to have a better idea about the sources of their inefficiency. It might be related to some administrative procedure or governmental regulation that is beyond the authority of the ports’ management.

2.4. Market concentration on maritime routes

The ongoing monopolization of the Container Liner Shipping Industry is a primary concern for a number of international and non-governmental organizations. UNCTAD (2017) has expressed concern regarding the reduction of direct services between individual ports. It was also suggested that that maritime competition authorities may need to review the regulatory regimes which currently apply to liner shipping (ICS, 2018). The findings in Chapter 4 show that the level of competition varies across regions, and it seems that the concentration of the market (average number of ships per carrier) is the highest with the connections between hub-ports.

Promotion of intra-regional trade, especially in Sub-Saharan Africa, would increase the direct individual port connections and would make the industry more sustainable. Chapter 4 has illustrated that the lowest level of market concentration is on intra-African, Africa-America, Africa-Europe and intra-Asian routes. On intra-African routes, the lowest average number of trips was recorded. The busiest routes on the other hand were intra-European and intra-Asian ones. The promotion of intra-African trade is among the recommendations from Danish Maritime Forum (2016) as well.

Restricting the possibility of container carriers to form Alliances and Conferences in order to establish price fixing and slot sharing agreements are policies that should be undertaken on a national and international level. Premti (2016) stated that “in the present situation, where countries all over the world are embracing competition as a means to their economic development, it appears that continuing to justify exemptions of traditional price-fixing liner conferences from competition laws, has become increasingly difficult”. The author also concluded that it is necessary to create a regulatory regime for non-ratemaking agreements in order to protect shippers from the abusive dominant position practices of the carriers. Furthermore, it should be highlighted that for some major economies, like the EU, it is easier to impose regulations in order to promote competition. On the other hand, developing countries need to implement a multilateral approach for protecting their interests. “Unfortunately, the international community’s efforts so far have not resulted in a standard legislative approach to liner conferences and other cooperative agreements, or in a globally endorsed, legally binding, multilateral agreement”(Premti, 2016).

Implementation of agreements related to the restrictions on the size of the new-build containerships could also be part of the solution to the growing consolidation of the industry. Another finding of Chapter 4 is the fact that the size of the containerships is the highest where the competition is the lowest. Due to the hub-and-spoke structure of the maritime network and the incentives of realizing economies of scale of container carriers, the highest levels of market concentration were recorded on the links between the biggest ports. As Hoffmann (1998) pointed out, the increasing relation between fixed and variable cost is the main reason for concentration in ports and shipping. Such regulations should be adopted by the UN and ratified by the biggest maritime nations: EU, USA, China, Japan and the Republic of Korea. Another solution might be a common agreement between the largest carriers and shipbuilders on setting some limits on the size of the ships. Stakeholders in the industry should find a way to regulate the capacity in order to make container shipping more sustainable.

3. Future research

The Container Liner Shipping Industry has entered a period of low growth. The market has become more monopolized and the size of the vessels has considerably increased. These trends imply that port efficiency, network optimization, the level of competition and freight rates will remain important issues in the years to come. Further consolidation of the market and potential new bankruptcies might also take place. However, the industry has a hidden potential which is the use of data that it generates. Actually, it is a challenge for researchers to obtain reliable up-to-date information related to ship movement, transported cargo per ship, port infrastructure, port productivity and others. Indeed, some data providers profit by selling this kind of data. The availability and the storage of such data in a proper format will allow scholars and professionals to better understand the topics developed in this dissertation and to also contribute to the sustainability of the shipping market. Data management is among the key priorities in the Master Plan on ASEAN Connectivity 2025. It states that:

“To progress towards transparency in data privacy and cross-border data sharing, the aim of this initiative is to enhance the data management frameworks in ASEAN. The initial step in achieving this objective is to establish transparency by mapping out data-management approaches

and requirements by all ASEAN Member States with reference to international best practices. A forum could then be established to share lessons on opportunities for ASEAN Member States to make progress and to explore areas of possible harmonization, culminating in an ASEAN digital data governance framework.(ASEAN, 2016b)”

It is expected that in the near future more data will be available and researchers will be able to develop new methods and approaches in order to better understand the position of each country and port in the Container Liner Shipping network.

Potential future research could include the use of another indicator as a proxy for container freight rates instead of CCFI. It is necessary to have time series for a longer period (more than 30 years) for the container segment. In this way, the findings of this dissertation could be double-checked. In addition, the cycles in the dry bulk and container segments could be compared. As demonstrated in Chapter 1, both markets have significant differences. Moreover, a variable which depicts the market concentration in the liner shipping industry (for example, the share of the top 10 companies in terms of slot capacity) as well as the variables reflecting economic activity worldwide could also be considered. Regarding the cycles in the container shipping market, a convenient mathematical tool to analyze the cyclical component of a time series is the Hodrick–Prescott filter, introduced by Hodrick and Prescott (1997). This method is used to obtain curve representation of a time series sensitive to long-term fluctuations. A similar approach is the Fourier Analysis where the general function is represented by sums of simpler trigonometric functions. The study of Chistè and Van Vuuren (2014) applied this methodology in the context of the dry bulk shipping market.

Regarding the network of container ports, a time series analysis is needed to better understand how the shipping network, as well as the role of different ports, has evolved throughout the years. A larger sample which includes small ports in Africa, Latin America and Asia would allow researchers to evaluate the intra-regional trade in developing regions. Considering climate change and the potential conflicts that might disrupt the supply chain, Graph Theory is a useful tool to analyze the resilience of the shipping network (Angeloudis et al. (2013), Kim et al., 2015). Additional studies on the resilience of the ASEAN shipping network are needed in order to ensure the sustainability of ASSM.

The environmental efficiency of container ports and terminals has become a hot topic. Actually, the DEA approach could be used to assess the input accesses and the output shortfalls of a given decision making unit (Tone, 2001). A slack-based measure DEA approach is similar to the classical DEA model, which assumes that producing more desirable outputs (i.e. renewable energy) relative to less inputs and undesirable outputs (i.e. CO₂ emissions) is a key factor for higher efficiency. It is a convenient tool in measuring the environmental performance of coastal cities, industrial regions and countries (Lee et al. (2014), Song et al., 2015, Apergis et al., 2015). Such studies are needed in ASEAN.

Competition between carriers on maritime routes, as well as the competition between shippers in a given country, need additional analyses. Time series on the market share per company in terms of sales, handled containers, or cargo weight are necessary in order to better understand the nature of competition. There is a lack of case studies on specific ports in ASEAN such as the case study on Jakarta conducted by International Transport Forum (2017). Additional qualitative research on the shipping market in Cambodia, Vietnam and Myanmar is needed due to their low scores in terms of the Liner Shipping Connectivity Index and the Trading Across Borders Index. Such case studies could provide potential reforms and policies that should be undertaken in order to ensure the inclusiveness and sustainability of the ASEAN shipping market.

The shipping industry is by far the most energy efficient means of transport. Driven by marginal efficiency, network optimization, and innovations, the industry has reshaped the world economy. Container shipping has great potential to contribute to the following UN development goals: decent work and economic growth, climate change, and affordable and clean energy. To do so, it is necessary to fully unleash the potential by responding to the new customer demand by making the sector more transparent, by properly regulating the competition and capacity, and by bringing growth to emerging economies. Along with the ongoing digitization of shipping, in the near future, data availability is expected to increase which could enable the IMO and other key stakeholders to better define policies that could bring long-term sustainability of the industry and prosperity for all.

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