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Container shipping line port choice patterns in East Asia
- The effects of port affiliation and spatial dependence

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Abstract: In the container shipping sector, many shipping lines are investing in ports and terminals. Although the literature generally agrees that shipping lines can benefit financially from such vertical investments, there are conflicting views on the impacts on different stakeholders, with limited empirical evidence nor solid data analysis. In addition to being an important managerial decision for shipping lines and their affiliated ports, this may become a policy issue because public infrastructure is expected to provide equal and fair access to all consumers. This study aims to enhance the understanding of the implications of shipping line-port integration by investigating its effects on the port call choices of shipping lines at the route level. Using data from East Asia, our correlation matrix of port-calls reveals significant spatial dependence in the port call patterns of shipping lines, and complex relationships between ports in a region, which can be substitutable, complementary or no significant relationship. Our spatial probit model estimation further suggests that carriers, whether based in East Asia or elsewhere, prefer to call at affiliated ports that they own either directly or indirectly via their alliance partners. Carriers tend to avoid calling at some ports with significantly overlapping roles on the same route but are likely to call at multiple ports that are less than 1200 km apart. Our findings also indicate that shipping lines prefer ports with adequate infrastructure and that the number of ports called on one route is constrained by the total transport time. We recommend that port authorities and local governments evaluate vertical integration on a case-by-case basis, because vertical integration could help secure some port throughput but nevertheless limit competition. Further studies on the shipping line-port integration's impacts on port handling efficiency and service quality would help policy formation on vertical integration in the maritime sector.

KEYWORDS: Port choice, Vertical integration, Container shipping, Spatial dependence

1. Introduction

In 2016, after the recovery from the 2008 financial crisis, the container shipping industry experienced a period of "low freight rates, low profitability, poor service levels, huge volatility and now more bankruptcies and loss of jobs" (Drewry, 2016). Although container shipping is currently experiencing a post-lockdown boom, shipping lines are continuing to search for ways to secure sustained competitiveness, particularly given the uncertainties still facing the industry.

Many of the world's leading shipping lines treat seaport terminals as an integral part of the transport chain, which they continuously invest in. This vertical integration enables shipping lines to upgrade the terminals and thus provide their customers with better services. Besides, the terminal operation is also a profitable independent business, which provides additional revenue streams to the affiliated shipping line's portfolio. A common ownership and operational model of container terminals is public ownership with private operations (Parola et al., 2013). Shipping lines often form joint ventures with different investors, such as local businesses, local-/state-controlled operators, and other/international terminal operators. The shipping lines often participate in operations and management through their subsidiaries or sister companies (Satta and Persico, 2015). For example, Shanghai port's Waigaoqiao Phase-4 terminals are operated by a joint-venture established by APM Terminals (Maersk's sister company) and Shanghai International Port Group (SIPG, supported by local government). The joint-venture operating Nansha port in Guangzhou is formed by APM Terminals, COSCO Shipping Ports Limited (COSCO's sister company), and a few local government-owned companies.

Despite the perceived benefits and industry acceptance, there have been mixed views on the effects of shipping line – port vertical integration, notably on port accessibility, service quality discrimination, and port competition.

For port accessibility, only a few shipping lines have declared that their terminals are for the exclusive use of their vessels, such as OOCL's terminals in Long Beach and Kaohsiung. Many more terminals affiliated with shipping lines claim that they provide the same services to all carriers. For example, COSCO Shipping Ports declared that its mission is to operate "Ports for ALL". Service quality can potentially be differentiated in terms of efficiency, service priority, charge, etc. Though intuitively, shipping lines may enjoy preferential service in their affiliated terminals, concrete evidence for such a claim has been quite limited. Some commentators have cast doubt on the comments of shipping line-affiliated terminal operators, arguing that they give favourable terms to their sister shipping lines and that the shipping lines naturally favour their own or affiliated terminals. For example, it has been noted that APM Terminals provides preferential treatment to its affiliated Maersk line, which has helped the latter to "gain heavily" (Anderson, 2014a, Anderson, 2014b). Moreover, Egan (2014) noted that Maersk has enjoyed significant cost benefits from APM Terminals. For example, Tanjung Pelepas, Maersk's hub in Southeast Asia operated by APM Terminals, had a much lower margin compared with its nearby competitor, PSA's Singapore terminal. Nonetheless, these claims are not conclusive. For example, the lower margin of Tanjung Pelepas may be due to the port's role as an entrant, regional competition, or other factors such as service quality. Maersk insisted that its superior financial performance is the result of its expanded network coverage and extensive business portfolio, and that its sister companies such as APM Terminals operate entirely at arm's length.

Shipping line–port vertical integration's impact on port competition is an important research question that has significant policy and business implications. There have been mixed views and arguments on this topic and rigorous analysis and solid evidence are needed to assess the real effects (Zhu et al., 2019, Jiang et al., 2020). On the one hand, a port is a key component of public infrastructure that supports trade and economic development in the neighbouring region (Homosombat et al., 2016). Thus, governments should ensure that their ports provide quality services to all users on an equal and fair basis. For example, the Australian Competition and Consumer Commission (ACCC) believes a vertically integrated monopolist is harmful to upstream or downstream competition.[1] On the other hand, there is also increasing competition among ports (Song, 2002, Lam and Yap, 2011, Wang et al., 2012) and the port operators endeavour to secure the services of shipping lines. Because many ports and terminals are publicly owned, they may be encouraged by governments to form various long-term arrangements or vertically integrate with shipping lines. For instance, OECD (2011) argued, though "*some shipping lines operate or own terminals within ports. This level of integration between the companies can provide them with incentives to restrict access to their facilities only to their own downstream operations",* such behaviour could lead to welfare benefit as *"it creates incentives for the upstream operator to invest in facilities that it would not have invested in if it had to allow downstream competitors to access them."*

In summary, the implications of shipping line–port integration are of great importance to the maritime industry, and need to be thoroughly examined to identify appropriate managerial strategies and public policies related to competition and regulation. Rigorous analysis based on real industry data should be conducted because of the mixed opinions and industry observations.

This study aims to contribute to this gap in the research by empirically examining how shipping lines' involvement in terminal operations relates to their port-of-call selection. We collect the data for routes connecting to the East Asia market and statistically test the relationship between shipping lines' port selection and various attributes of port services, with a focus on the ownership of the terminals and their vertical relationships with the shipping lines. The empirical analysis with a spatial probit model confirms that shipping lines are inclined to call at ports they are involved in, regardless by themselves or their alliance partners. Meanwhile, we examine the possible dependence among ports that are geographically proximate, with explicit control of possible spatial dependence within the port clusters along shipping routes. It is found that carriers tend to call at multiple ports in one region, but not those with significantly overlapped catchment areas. Ports in the same region could have different relationships to each other. Those with better infrastructure are more attractive to shipping lines, and a trade-off is observed between the shipping route's total transport time and the number of calling ports.

The remainder of this study is structured as follows. Section 2 reviews the literature on port choice and vertical integration in the container shipping industry. Section 3 describes the data and methods used. Section 4 presents the main empirical findings. Section 5 provides discussions regarding the results, and Section 6 is dedicated to concluding remarks and discusses the limitations and possible future extensions.

[1] Source: https://www.accc.gov.au/speech/accc-perspectives-on-transport-issues

2. Literature

Two streams of literature are related to this study. The first stream covers the factors that influence a shipping line's port choice. The second stream is about vertical integration in the container shipping industry. Shipping lines' route design and port call decisions are complex and influenced by numerous factors. There is no consensus on which party is the actual decision-maker. For example, some studies have treated port selection as a result of the shippers or freight forwarders' choice of carrier (Slack, 1985, Magala and Sammons, 2015), whereas numerous other studies have focused on the shipping lines' port choice criteria. In this study, we treat shipping lines as the decision-makers, who act as key customers of ports and provide transport services to shippers and forwarders (Tongzon, 2009).

We first review the literature on shipping lines' port selection patterns, and the key variables that should be included in our model. Various factors have been investigated in the literature. Martínez Moya and Feo Valero (2017) categorized the factors into those that can be controlled by the port authorities and those not under their control. Factors such as the performance and connectivity of ports and the fees that they charge are under the control of the port authorities. Transport costs, the inland and maritime distances to/from a port, and a port's geographical location are the key factors beyond the control of the port authorities. Although stakeholders cannot influence these factors, they can improve the efficiency of the ports by enhancing their intermodal connectivity, service frequency and port charges. Technical indicators such as crane productivity (Steven and Corsi, 2012, Tongzon, 2009) and variables that measure customer satisfaction and port achievement are considered to reflect the effectiveness and efficiency of ports (Brooks and Schellinck, 2013).

In addition, Notteboom et al. (2017) stressed the impact of shipping lines behaviour, which is beyond the port authorities' control but could affect port selection through the formation of shipping alliances and their vertical expansion into port terminal operations. Alliances can help carriers to pool their vessels, terminals, and equipment, and thus improve their profitability through joint scheduling and chartering (Wang, 2015). Table 1 shows the world's top eight shipping lines and the related terminal operators.[2] Except for Hapag-Lloyd, all of the carriers have their own/sister terminal operation companies. The formation of operators such as APM Terminals and COSCO Shipping Ports illustrates their parent companies' strategic moves to expand their business profiles by including port operations.

<Table 1 about here>

The second stream of the reviewed literature is about vertical integration in the container shipping industry. Shipping lines may enter into vertical arrangements with port and terminal operators to secure a competitive position by gaining more control over other stages of the transport network (World Bank, 2007). Notteboom and Rodrigue (2009) explained that when it is challenging to further reduce maritime costs, carriers can gain some competitive advantage

[2] Table 1 provides further evidence of the important roles played by shipping alliances. After a series of mergers and acquisitions and alliance formations, by September 2018, members of the world's top three alliances were also the top eight carriers in the container line service market, accounting for 77.5% of the market capacity (Alphaliner, 2018).

by controlling other non-maritime costs via vertical involvement. Lun et al. (2010) considered the inadequate capacity in some congested areas and suggested that carriers can reserve some terminal capacity in these regions.

Terminal operators are also playing a more important role as a result of the ever-larger vessels being used by shipping lines and the stricter requirements for berthing, quay cranes, and container management (Lane and Moret, 2014). Investing in terminal operations can help shipping lines to secure reasonable port charges for their mega-ships, and preserve the benefits of the scale economies they achieve at sea (Van de Voorde and Vanelslander, 2010). Turner (2000) and Kaselimi et al. (2011) discussed the implications of shipping lines' dedicated terminals, and pointed out that the carriers involved can enjoy shorter queueing times, although at the cost of the overall efficiency of their competitors and the ports. Moreover, the dedicated capacity can improve the business networks of shipping lines (Soppé et al., 2009). Apart from hosting their sister shipping lines, these port and terminal operators usually cooperate with other carriers to maximize their profits (Notteboom and Rodrigue, 2012).

The downsides of vertical integration are related to the integrated company's monopoly power. Frémont (2010) suggested that shipping lines' entrance to upstream and downstream markets would threaten existing terminal operators and freight forwarders. Though integrated service would to some degree benefit shippers with higher service quality, it would also make customers heavily reliant on the integrated company as a monopolist. There are also concerns about the port authority's control over the market (Van de Voorde and Vanelslander, 2010) and the port's catchment area (Ferrari et al., 2015).

Some studies applied analytical models to investigate the relationship between shipping line and terminal operators, which attempt to show the full picture of not only the vertically integrated entity but also other competitors and the whole market. Álvarez-SanJaime et al. (2013) categorized the different ways that carriers use their own terminals and discussed whether shipping lines should use their terminals exclusively or not. They recommended that carriers use their terminals non-exclusively to pursue maximum profits and stated that other shipping lines could benefit from differentiated product portfolios by using these terminals. Zhu et al. (2019) considered a model with one shipping line and one terminal operator. It is shown that the integrated shipping line is always better off, albeit at the expense of non-integrated competitors. Without intra- or inter-port competition, social welfare can be improved by integration.

Wang and Liu (2019) and Jiang et al. (2020) expanded this issue in an integration-to-integration competition model. They found that the shipping line and port are always willing to integrate, but the interest of other competitors and social welfare could be harmed. Zheng et al. (2021) introduced uncertainty in the shipping line's port investment problem. The study concluded that, without the government's proper guidance, the shipping line's investment plan is not always in line with the social optimum.

Many studies have examined the topic of port choice (Lau et al., 2013, 2017). However, they have mostly focused on optimal network design and schedule planning, with recent studies examining the implications of issues such as increased fuel prices, emission regulations, and infrastructure investments (Imai et al., 2009, Shintani et al., 2007, Notteboom and Vernimmen, 2009, Meng and Wang, 2011, Tu et al., 2018, Dai et al., 2018, Bell et al., 2019). Few studies have examined the effects of vertical integration or port operations. Notteboom et al. (2017)

conceptually analyzed the interplay between shipping lines' alliances, terminal operations, and port selection patterns among northwestern European ports, and found that in most cases the shipping lines and their alliance partners called at the ports they were involved in. As much of the research has been based on the analysis of binary data, controlling for multiple factors simultaneously is not straightforward. Our study throws new light on this critical issue and extends the analysis beyond Europe to the case of East Asia. We explain the data and method used in our study in the following section.

It is generally agreed that shipping lines can benefit financially from their vertical investment in ports and control of the terminals. However, different stakeholders have various views on whether ports and terminals should provide better/preferential services to the carriers they are affiliated with. As mentioned above, this is not only an important managerial decision for shipping lines and their affiliated ports, but may also become a policy issue because public infrastructure is expected to provide equal and fair access to all consumers. Yet few studies have been able to empirically check these claims, because it is difficult to collect detailed operational and performance measurements across ports and terminals. Even if such data were available, the differences might be ascribed to operator strategies, country/region/port characteristics, or intentional port differentiation (Zhuang et al., 2014).

This study examines whether shipping lines' vertical investments in ports are intertwined with their decisions on ports-of-call and route configurations. Our contribution to this topic is twofold: Our study provides fresh insights into the implications of shipping line–port integration. Although vertical integration, in general, has been extensively discussed in the economics literature, few empirical tests have been conducted in the maritime industry. In addition, we contribute to the literature on shipping route choices and network configuration by quantifying the effects and necessity of considering the ports' vertical involvement status.

3. Data and method

3.1 Data sampling and sources

We collected the routes of the world's top nine shipping lines in 2018 that connect East Asia with other regions. We have also included OOCL, as it operates independently from COSCO under the dual-brand strategy. The shortest one-way route distance in our sample was 3396 nautical miles (nmi) linking Yokohama to Dutch Harbor, and the other relatively short routes mainly connected East Asia with ports in West Asia including those in India, Pakistan, and Sri Lanka. Routes serving East Asia and South and Central America had the longest one-way distances, which were greater than 12,000 nmi. In total, we collected data on 421 routes, of which 65 were from the 2M Alliance, 237 from OCEAN, and 119 from THE Alliance, respectively (Table 2).

<Table 2 about here>

We included ports in East Asia that have been called by at least one of the nine shipping lines, and further categorized these ports into six clusters: northern China (NC), eastern China (EC), southern China (SC), Korea (KOR), Japan (JAP), and Taiwan (TW) (Table 3). In total, there are four ports in northern China, two in eastern China, and six in southern China. Due to its geographical and political proximity to mainland China, Hong Kong was included in the southern China cluster. The clusters of Japan, Korea, and Taiwan comprise eight, four, and three ports, respectively. We retrieved the ports' TEU throughputs in 2016 and 2017 from the websites of the terminal operators and port authorities. We obtained the country level GDP data for Japan, Korea, and Taiwan from the World Bank, and the provincial GDP figures for the Chinese clusters from the National Bureau of Statistics of China. Xu (2016) categorized the catchments of the major Chinese ports as their "hinterlands," and we used the same definition to describe the port clusters included in each region.

<Table 3 about here>

3.2 Variables

Our work investigates whether the involvement of shipping lines/alliances in terminal operations influences their ships' calling at those ports. Therefore, in the spatial regression, we use the dependent variable *poc*, which takes the value of 1 if the port is called at on that specific route, and 0 otherwise. Our key independent variables are the dummy variables *ownt* and *alliancet*. *ownt* takes the value of 1 if and only if a terminal within the port is vertically integrated with the shipping line. When a terminal within a port is integrated with at least one alliance member of a shipping line but not with the shipping line itself, the variable *alliancet* takes the value of 1, and 0 otherwise. Ideally, all variables should be defined at the terminal level. However, due to data availability, we were only able to collect route and port information at the port level.

The other independent control variables are chosen based on literature review and data availability. They can be categorized into four groups. The first group comprises shipping line-specific variables related to the total fleet size and TEU capacity of the carriers, which are used to control for heterogeneity across the shipping lines. Second, route-specific variables depicting the route length, one way voyage time, number of called ports, and the economic conditions in the target market are used to control for the route-specific characteristics. The third group comprises port-specific variables relating to the annual throughput. Finally, we include cluster-specific variables to reflect the hinterland information about the port clusters. The variables are listed in Table 4. An example of variables for two routes is presented in Appendix A.

<Table 4 about here>

3.3 Method of analysis

Probit models have been extensively used in route entry studies. In this study, we also include spatial variables to detect and control for the possible spatial dependence among nearby ports. A weight matrix W is introduced, and each element w_{ij} of the matrix represents the geographical relationship between neighbouring ports i and j. When all of the elements on the main diagonal are zero, each row of the matrix is standardized. The row-standardization ensures that all of the weights in matrix W are between 0 and 1, and the elements of each row sum up to 1. As explained below, we use different types of spatial weight matrices.

Two specifications of spatial models have commonly been used in the literature, namely the spatial autoregressive lagged dependent variable model (SAL) and the spatial autoregressive error model (SEM) (Merkel, 2017, Fleming, 2004). When the spatial coefficient is a parameter of interest, the SAL model is more commonly applied. Following the SAL variant of the conventional probit model proposed by LeSage and Pace (2009) and LeSage et al. (2011), we specify the underlying model in matrix form as follows:

$$\pi = \rho W\pi + X\beta + \varepsilon, \tag{1}$$

where π is the (vector of) latent profit variable for the shipping line that determines whether a port is called at or not. X is the matrix of the independent variables associated with the parameter vector β . The spatial lag $W\pi$ is a linear combination of the neighbouring observations and the spatial weights matrix. The spatial scaler ρ measures the intensity of the spatial interdependency, where a positive value means similar values are gathered; otherwise, the neighbouring values are negatively related to each other.

As the latent variable π is not observable, a commonly accepted assumption is that shipping lines will only call at ports if it is profitable to do so. This leads to a probit model with a binary variable y_i defined as:

$$y_i = \begin{cases} 1 \; if \; \pi_i \geq 0 \\ 0 \; if \; \pi_i < 0 \end{cases}. \tag{2}$$

Note that y_i reflects a shipping line's decision to call at a port or not and is thus observable. With Eq. (1), we have:

$$\pi = (I_n - \rho W)^{-1} X\beta + (I_n - \rho W)^{-1} \varepsilon. \tag{3}$$

In this study, two types of spatial matrices are introduced. The first is related to the defined port clusters. Two matrices are specified, denoted as W^{cb} and W^{cd}. In the binary-valued cluster matrix W^{cb}, the value of w_{ij}^{cb} is set to 1 if both ports i and j ($i \neq j$) are in the same predefined cluster, and 0 otherwise. Instead of binary values, the elements in the distance weighted cluster matrix W^{cd} are set to be the inverse of the distances between ports in the same cluster and 0 otherwise (see Appendix B for further explanation). Intuitively, the spatial dependence between two ports, if any, diminishes the further they are apart. Therefore, the inverse of the port distance is used. Both of the matrices are subsequently row-standardized before running the regression.

Although the first spatial matrix reflects the generally accepted industry definition and classification of port clusters, it may nevertheless be subjective. The second type of spatial matrix used in our analysis is defined by the neighbouring radius. Different radius values are tested, as reported in Table 7. For example, in matrix W^{r400}, only ports within 400 km of the target port are considered. That is, we check the possible spatial dependence of ports that are within 400 km of each other. As in the case of the port cluster matrix, the values are first set to the inverse of distances and then row standardized.

4. Main empirical results

We first present the tetrachoric correlations to identify some preliminary results regarding the shipping lines' port of call patterns. Although this simple correlation does not control for other factors, it is based on minimum assumptions and clearly outlines whether the shipping lines tend to call at two ports sequentially on the same route, or tend to avoid the other once a port is called. We then present the results of the probit model, which characterizes the factors that influence the shipping lines' route and port-of-call patterns.

4.1 Port call correlation on route level

The tetrachoric correlation coefficient is used to describe the linear relation between two normally distributed continuous variables that have been measured in the dichotomous scale (Bonett and Price, 2005). Table 5 presents the tetrachoric correlation matrix of the selected ports-of-call, which offers insight into the shipping lines' route design patterns. A positive correlation implies that a shipping line is likely to call at the two ports sequentially or that the two ports tend to be "complementary." A negative correlation suggests that the shipping lines tend to avoid calling at two ports on one route or that they appear to be "substitutable" for each other. Table 5 shows some interesting patterns. For the ports in southern China near the Pearl River Delta (i.e., Shekou and Yantian in the city of Shenzhen, Nansha port in the city of Guangzhou, and Hong Kong), the two ports in Shenzhen appear to be substitutable as evidenced by their significantly negative correlation. This is intuitive as the two ports have a significant overlap in their hinterlands. However, both ports also have a complementary relationship with Hong Kong. That is, routes that call at the Shenzhen ports are likely also to call at Hong Kong. This is an interesting finding because it provides some support to the "co-opetition" hypothesis proposed for the ports in this region in previous studies (Song, 2002, Song, 2003). It was suggested that ports of Shenzhen and Hong Kong can gain mutual benefit by co-operative structural transformation, which nevertheless has not been validated until now with empirical industry data. Guangzhou (Nansha) has no significant correlation with the other three ports in its cluster, suggesting that it is significantly differentiated from the other ports despite its geographic proximity. Notably, all four Pearl River Delta ports are not likely to be called at when the routes are serving Japanese or northern Chinese markets, and, except for Nansha, they are more likely to connect with Taiwanese ports.

Among the northern China ports, routes calling at Xingang and Lianyungang are also likely to serve the other two ports in the region, Qingdao and Dalian. The four ports also have some significant port-specific correlations with the Japanese and Korean ports, for example, Qingdao with Yokohama, Osaka, and Busan; Dalian with Kwangyang; Xingang with Incheon and Kwangyang; and Lianyungang with Incheon. Shanghai and Ningbo in eastern China are two of the world's five busiest container ports. They are likely to be called together in one route and also show some complementarity with Qingdao and Osaka. They also have significant negative correlations with most of the selected ports in East Asia, which confirms the finding of Wu et al. (2017) that container ships visit fewer clusters but not necessarily fewer ports.

For Japanese ports, shipping lines tend to make a choice between Tokyo and Yokohama, which are negatively correlated, although they are likely to call at more than one port when serving the Japanese market. That is, a shipping line often calls additional Japanese ports on the routes of calling either Tokyo or Yokohama. It is also notable that Yokohama is significantly connected with the Korean ports of Busan and Kwangyang. As aforementioned, Korean ports are better connected with northern Chinese ports, while Taiwanese ports have more connections with ports in the Pearl River Delta. Although these observations identify some interesting port-of-call patterns among the major shipping lines, they do not offer much explanatory insight. Therefore, we report the results of our probit model in the following section.

<Table 5 about here>

4.2 Empirical findings of the probit model

4.2.1 Models with cluster spatial matrices

To ensure the robustness of estimation and to better identify the influence of the individual variables, Table 6 presents the results of the different specifications of the probit model. Spatial variables are included in the estimations of the first four models. In models 1a and 1b, spatial matrix W^{cb} is introduced to reflect the route's port-of-call situation within the port clusters defined following industry practice. Models 2a and 2b are estimated using spatial matrix W^{cd}, which also reflects the inter-port distances within the clusters. Models 1a and 2a test the significance of the controlled independent variables and spatial variables. In comparison, the other two models (1b, 2b) include the target variables capturing the vertical ownership status of the ports. The last two models classify the carriers into Asian and non-Asian companies to investigate their different route design patterns in East Asia. Intuitively, major shipping lines based in Asia may have extensive local networks, whereas non-local carriers are expected to serve long-distance routes with large vessels. As a result, it is useful to run two separate estimations for different groups of carriers.

Although there are some differences in the coefficient values and significance levels across the different specifications, the overall estimation results appear to be consistent. In models 1b and 2b, the target independent variables, *ownt* and *alliancet,* are both significant at the 0.01 level and have the expected positive signs. This indicates that when designing their routes, the carriers are more likely to include ports in which they have an ownership stake, either directly, via their own sister companies, or indirectly, via their alliance partners. The four spatial scalers ρ are positive and significant at the 0.01 level, indicating significant spatial dependence in the shipping lines' port of call patterns.

The control variable *htldports* indicates that a port is less likely to be called at when there are more alternative ports in the same cluster as defined according to industry practice. This is intuitive, as ports within a cluster generally share the same hinterland, and thus tend to be substitutable for each other. This further highlights the somewhat surprising complementarity identified between the ports in Shenzhen and Hong Kong, which is probably due to the unique position that Hong Kong occupies as an international transfer-hub and a trade gateway for the region. The variables *owpoc* and *owday* are significantly positive and negative, respectively. This suggests that *ceteris paribus*, a port is naturally more likely to be called at if more destinations are scheduled on a route but the effect is constrained by the total travel time. This reflects an important trade-off in container shipping, namely that by increasing the size of their ships for the sake of scale economy, shipping lines gain an incentive to aggregate their container volumes, possibly by calling at more ports. However, a larger vessel size also leads to higher unit handling cost at the port, leading to diseconomies of scale (Yip et al., 2012, Yahalom and Guan, 2018). In addition, shipping lines are also motivated to limit the number of port-of-calls so that to control the total transport time. Accordingly, shipping lines have to balance these two effects when planning their routes and networks, which is consistent with the positive and significant coefficient of the variable *sts*. As the number of ship-to-shore cranes increases, ships also spend less time in port, which increases the likelihood of the port being called at. ht has a negative and significant coefficient, indicating shipping lines would choose ports with less handling time. The processing speed of port operators is a key service attribute that is highly appreciated by shipping lines.

In the two extension models presented in the last two columns of Table 6, the distance-based spatial matrix W^{cd} is used. The two specifications are run separately for the shipping lines based on the location of their headquarters. The Asian carriers comprise COSCO, OOCL, Evergreen, ONE, and Yangming, whereas the non-Asian carriers comprise Maersk, MSC, CMA CGM, and Hapag-Lloyd. The target variables, *ownt* and *alliancet*, are both significant at the 0.05 level regardless of whether they are based in Asia, again confirming the shipping lines' strong preferences for their own or affiliated ports. The estimation results for the spatial variable ρ suggest that Asian carriers tend to call at multiple ports within a cluster, whereas no such pattern is observed for the non-Asian carriers. Partly due to the cabotage policy, Asian carriers tend to have more extensive network coverage in their "home field" and to be involved in many port operations, which probably explains the observed pattern. For example, COSCO in China, Evergreen and Yangming in Taiwan, and ONE in Japan have all invested in numerous ports, and all have extensive networks in the region. The non-Asian carriers have less local involvement, and thus tend to invest in selected ports within a cluster and make full use of them. This explains why *ownt* and *alliancet* are positive and significant for the non-Asian carriers but do not show significant spatial dependence.

<Table 6 about here>

4.2.2 Models with neighbouring radius spatial matrices

Although port clusters are commonly used and accepted in the shipping industry, the definitions of the clusters may be subjective. To check the robustness of our specification and further examine the possible spatial effects, we test models with spatial matrices defined by the radial distance. The minimum distance between ports in our sample is 20.4 km (11.0 nmi), and the maximum distance is 3113.9 km (1681.4 nmi). Therefore, eight specifications with intervals of 400 km (216.0 nmi) are tested; the results are shown in Table 7. For example, the first model considers the spatial effects for ports less than 400 km apart, whereas the second column tests the possible spatial effects for ports that are 400-800 km apart.

For the eight models tested, the coefficients of *ownt* and *alliancet* are significant and positive, which suggests that the shipping lines have strong preferences for their own and affiliated ports. The signs of the spatial scalers reflect the spatial patterns of the shipping lines' port calls in East Asia. When the neighbouring radius is within 1200 km, the signs of the scalers are all positive and significant at the 0.01 level. The tests of the spatial matrixes for the 1200 km to

1600 km intervals show no significant effects.[3] When the radius is expanded beyond 1600 km, the scaler becomes significant again, but with negative signs. These results suggest that in East Asia, carriers tend to focus on one region, which is consistent with the patterns observed in the correlation table (e.g., a route serving northern China is unlikely to also include ports in southern China or Taiwan). Finally, the estimation results suggest that shipping lines tend to call at multiple ports within a cluster of up to 1200 km apart, and are unlikely to call at faraway ports on one route.

<Table 7 about here>

5. Discussion

Shipping lines are expanding their business portfolios and becoming increasingly involved in port and terminal operations. Although the literature has generally agreed shipping lines can benefit financially from their vertical investments in ports and terminals, there are varying views on whether prioritised services should be offered. In addition to being an important managerial decision for the shipping lines and affiliated ports, this may become a policy issue because public infrastructures are expected to provide equal and fair access to all consumers. As reviewed in previous sections, there has been no concrete evidence on whether favourable or discriminatory treatments were offered with vertical integration, and there has been no agreement that in theory, whether vertical integration harm competition or welfare. Some previous studies endeavoured to examine this issue with analytical models (Álvarez-SanJaime et al., 2013, Wang and Liu, 2019, Zhu et al., 2019, Jiang et al., 2020, Zheng et al., 2021), but their different model set-ups and assumptions lead to various conclusions.

Therefore, it is important to conduct an empirical analysis to reveal actual industry practices. As explained in the introduction and literature review, examining port call patterns helps to get insights into vertical arrangements' effects on port competition and liners shipping networks.

It should be cautioned that the proposed model and cross-sectional data do not lead to a definite answer of causality. Admittedly there could be other interpretations of the association between shipping lines' vertical investment and route design. That said, it is reasonable that shipping lines' route design is influenced by their port operation involvement. Route design is at the tactical level while port involvement is at the strategic level. Once shipping lines' port investment is made, it could not be changed in a short time. Therefore, when designing the route, carriers are more likely to consider the cost and benefit of one port on the routine operational level, instead of considering any change of the sunk port investment. Our empirical analysis thus identifies a port call preference brought by the shipping lines' vertical investments in ports and terminals, which is in accord with the results from Notteboom et al. (2017)'s study in European ports.

For the integrated shipping line and terminal operator, the benefit is twofold. First, it is logical that they can receive favourable terms in their related port and get advantages in terms of better service quality (Anderson, 2014a, Anderson, 2014b, Egan, 2014). Second, they are also motivated to fully utilise the port capacity by serving other shipping lines and enjoy the profitability of terminal operation businesses. These findings can provide different managerial

[3] To illustrate these effects, note that the distance between the ports of Shanghai and Xiamen is 1083.4 km, and the distance between Shanghai and Hong Kong is 1564.9km.

or policy recommendations to different stakeholders (e.g. the port authority vs. local government). If securing throughput or wresting market share from existing competitors is the top priority, then a vertically integrated port could be a good choice. Terminals in Singapore, Khorfakkan and New York/New Jersey lost throughput because some of their major shipping lines partners like Maersk and Hapag-Lloyd decided to shift service calls to nearby integrated ports. If the port authority and local government target fair competition and promote regional development, then quality access for all carriers would be essential. This is more likely to happen when the port serves as an irreplaceable gateway to a market. Although shipping lines and ports may have incentives to provide preferred services to affiliated customers, such discriminative practices would have negative impacts on the hinterland economy. The local government should scrutinize vertical integration in such situations.

In light of the economic shocks caused by the recent pandemic and political frictions, the demand for container shipping has gone down in many markets although carriers mostly remain profitable (Notteboom et al., 2021). It is worthwhile to investigate if shipping lines would prioritize calling at their affiliated ports while reducing the total liner services. Due to data limitations, our current study does not directly provide statistical evidence on this issue. There are however some industry observations. During the pandemic, Maersk terminated the agreement with a New York terminal and subsequently shifted services to APM Terminal's facilities in Port Elizabeth, New Jersey.[4] Besides, with the overall downturn of terminal profitability, Maersk's affiliated terminals in Russia and Vietnam managed to generate more revenue than last year by serving 2M alliance's routes.[5] Vertically integrated terminals indeed secure some transport volumes in such challenging situations.

Our study also suggests that ports in a region could have complex relationships with each other. For example, although we do find supporting evidence that adjacent ports are often competitive and substitutable to each other (e.g. Yantian vs. Shekou; Tokyo vs. Yokohama), they can also be complementary (e.g. the Yantian and Shekou ports in Shenzhen vs. Hong Kong; Xingang and Lianyungang vs. Qingdao and Dalian, respectively; and the complementary relationships identified for ports in North China, Korea and Japan). Our study provides empirical support to the "port co-opetition" concept with rich details. Song (2002, 2003) proposed that ports in mainland China and Hong Kong can have both cooperative and competitive relationships (i.e. complementary and substitutable at the same time). Our analysis further suggests that certain port-pair within a region can be non-related. Specifically, the two ports in Shenzhen are substitutable to each other, but complementary to Hong Kong. The Nansha port in Guangzhou seems to be substantially differentiated from the other three. Such results suggest that ports' relationship is influenced not only by geographic location, but also their roles in supply chains, services related to trade and shipping, and their different roles in the global shipping network (i.e. shipping hub status). Such empirical results suggest more complex relationships between ports and are new to the literature. With such complexity in mind, the government should be more prudent and review empirical evidence for the relevant markets before formulating policies over vertical integration, as the effects of integration also depend heavily on market structure, port competition (or co-opetition), and service differentiation. This calls for case-by-case analysis in policy analysis.

[4] Source: https://shippingwatch.com/Ports/article12091777.ece

[5] Source: the case of Vietnam: https://www.porttechnology.org/news/apmts-vietnam-terminal-wins-place-on-2m-route/; the case in Russia: https://shippingwatch.com/Ports/article12366585.ece

It should be noted that regulators have alternative policy options even if competition concerns are validated for vertical integration. They may forbid vertical integration if two ports are quite substitutable. For example, the Turkish government doesn't allow operating rights at the Port of Ismir and the Port of Mersin to be transferred to liner transport or ship broker services. To avoid a port being fully integrated and controlled by one shipping line, OECD (2011) advised that a regulator can split terminals in a port to different operators, or force the divestiture of individual ports if a common owner controls multiple ports in a region. Another alternative option is direct price regulation, which is appropriate where a port or specific port service can be classified as a natural monopoly.

6. Conclusion

This study aims to contribute to the understanding of shipping line-port integration by investigating its effects on the port selection of shipping lines. This is achieved by analyzing the correlation matrix between port calls, and empirically estimating a probit model of the route choices of shipping lines that takes into account the possible spatial dependence effects. Using data from East Asia, our correlation matrix of port-calls confirms that there is significant spatial dependence in the lines' port selection patterns. The estimation results of our spatial probit model further suggest that (a) shipping lines, whether based in East Asia or other regions, always prefer to call at affiliated ports that are directly owned by themselves or indirectly via their alliance partners. (b) Carriers are likely to call at multiple ports that are less than 1200 km apart. Specifically, Asian carriers tend to call at multiple ports in a region (i.e., within a 1200 km radius), whereas non-Asian carriers are likely to limit the region's number of ports-of-call on one route. (c) Shipping lines tend to avoid calling at ports with significantly overlapping roles on the same route, or ports that are too far apart (i.e., more than 1600 km apart in our sample). (d) shipping lines prefer ports with good infrastructure, and the number of ports called at in one route is constrained by the total transport time. Finally (e), ports in a region could have complex relationships with each other, that could be (combination of) substitutable, complementary, or not closely related/differentiated. The inter-port relationship is influenced not only by geographic location, but possibly also their roles in supply chains, services related to trade and shipping, and their different roles in the global shipping network.

These findings, together with the conclusions obtained in previous studies, suggest that vertical integration in the maritime industry is a complex issue and subject to the influences of multiple factors. The appropriate government policy over vertical integration much depends on market structure, service differentiation, and port competition, which calls for case-by-case analysis. Although the conclusion seems not straightforward and clear-cut, it is perhaps useful to note that vertical integration and arrangements have also attracted considerable attention and careful studies in the aviation industry. For example, Fu et al. (2011) reviewed various airport-airline vertical relationships and regulatory implications. Fu and Zhang (2010), Zhang et al. (2010) and Yang et al. (2015) analysed the implications of airport-airline revenue sharing. Barbot (2011) and Barbot et al. (2013) examined vertical contracts and possible collusion between airlines and airports. In general, these studies found that vertical arrangements between airlines and airports can be a major source of welfare gains, but can nevertheless distort market competition. Because the results are complicated and two-sided, these studies caution against premature strict regulation. Instead, governments should monitor such practices, and make the vertical arrangement details transparent to the industry and outsiders. This would discourage anti-competitive behaviour. Similar conclusions may hold for the maritime industry, yet more in-depth investigations are needed considering the significant differences between the maritime and aviation sectors.

As one of the first to empirically examine shipping line-port integration's implications, our study nevertheless has a number of limitations. First, due to limited data availability, we are unable to control for the total shipping capacity and vessel size at the route level. It would be ideal to control for service frequency and vessel size when such data are available in the future, preferably as a panel dataset. Otherwise, port-specific conditions may only be controlled using fixed-effect models or port-specific variables, which nevertheless call for a larger sample size. Second, although we control for the effects of shipping alliances, we are unable to explicitly control for the possible common ownership between ports and terminals due to the complex ownership structure of certain ports in the region. To fully address this issue, data availability and quality need to be both improved. Currently, the publicly available information on carriers' port-of-calls is not detailed to the terminal level. Thirdly, we are unable to determine the direction of causality from the data. Possible ways of filling this gap include adopting statistical inferences such as the Granger causality test with data in more time periods, and conduct case studies to compare a port's container throughputs before and after the shipping line's investment. Extended studies on this important topic should be conducted when more detailed data are available.

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Table 1 WORLD TOP EIGHT SHIPPING LINES' RELATED TERMINAL OPERATORS

Shipping line (Market share)	Terminal operator	Relation	Number of terminals
Maersk (17.8%)	APM Terminals	Sister company owned by The Maersk Group	73
MSC (14.4%)	Terminal Investment Limited (TIL)	Established fully by MSC	34
COSCO (12.5%)	COSCO Shipping Ports	Sister company owned by The COSCO Group	31
	OOCL's two affiliate companies	Fully owned OOCL subsidiaries	2
CMA CGM (11.7%)	Terminal Link	Capital is held by CMA CGM (51%) and China Merchants Holdings International (49%).	27
	CMA Terminals	Fully owned CMA CGM subsidiary	
Hapag-Lloyd (7.0%)	N.A.	N.A.	N.A.
ONE (6.8%)	Ceres Terminals	Fully owned NYK subsidiary	11
	Nippon Container Terminals	Established partly by NYK	
	TraPac	Fully owned MOL subsidiary	10
Evergreen (5.2%)	N.A.	N.A.	9*
Yang Ming (2.8%)	N.A.	N.A.	7*

* Limited information available, number could be incomplete
Source: authors' compilation based on information provided by shipping lines

Table 2 SHIPPING LINE AND ALLIANCE INFORMATION OF COLLECTED ROUTES

Shipping line	*Number of routes*
2M	**65**
Maersk	37
MSC	28
OCEAN	**237**
CMACGM	65
COSCO	72
EG	53
OOCL	47
THE	**119**
HL	39
ONE	46
YM	34
Total	**421**

Source: authors' compilation based on information provided by shipping lines

Table 3 INFORMATION OF COLLECTED PORTS

Port	***Cluster***	***N.o. called routes***	***Volume in 2016 (kTEU)***	***Volume in 2017 (kTEU)***	***N.o. STS cranes***	***Country***	***Hinterland GDP in 2016 (bUSD)***	***Hinterland GDP in 2017(bUSD)***
Qingdao	NC	147	18,010	18,262	111	China	3,246	3,538
Dalian	NC	22	9,614	9,707	70	China	3,246	3,538
Xingang	NC	51	14,490	15,040	63	China	3,246	3,538
Lianyungang	NC	11	4,703	4,710	99	China	3,246	3,538
Shanghai	EC	319	37,133	40,233	80	China	5,018	5,470
Ningbo	EC	284	21,560	24,607	35	China	5,018	5,470
Xiamen	SC	100	9,614	10,380	79	China	3,832	4,139
Fuzhou	SC	9	2,650	3,007	155	China	3,832	4,139
Yantian	SC	159	13,021	14,027	102	China	3,832	4,139
Shekou	SC	166	10,958	11,181	23	China	3,832	4,139
Nansha	SC	60	18,859	20,370	75	China	3,832	4,139
Hong Kong	SC	129	19,813	20,770	22	Hong Kong	3,832	4,139
Tokyo	JAP	32	4,250	4,500	73	Japan	4,939	4,872
Kobe	JAP	24	2,801	2,924	28	Japan	4,939	4,872
Yokohama	JAP	35	2,658	2,926	32	Japan	4,939	4,872
Nagoya	JAP	15	2,658	2,784	28	Japan	4,939	4,872
Osaka	JAP	14	2,216	2,326	20	Japan	4,939	4,872
Hakata	JAP	1	897	920	9	Japan	4,939	4,872
Shimizu	JAP	6	541	571	5	Japan	4,939	4,872
Sendai	JAP	5	246	260	4	Japan	4,939	4,872
Busan	KOR	180	19,456	20,493	114	Korea	1,411	1,531
Incheon	KOR	2	2,679	3,050	23	Korea	1,411	1,531
Kwangyang	KOR	13	2,224	2,230	21	Korea	1,411	1,531
Ulsan	KOR	2	423	217	5	Korea	1,411	1,531
Kaohsiung	TW	111	10,464	10,271	66	Taiwan	531	579
Taipei	TW	21	1,477	1,561	13	Taiwan	531	579
Keelung	TW	16	1,388	1,418	30	Taiwan	531	579

Table 4 DESCRIPTION OF CONTROL VARIABLES

Code	***Variable***	***Average***	***Min***	***Max***	***Comment and source***
Target variables (For 421 routes, 27 ports)					
ownt	If the port is vertically integrated by the shipping line	0.167	0	1	Source: Shipping lines' websites
alliancet	If port is integrated with at least one alliance member of a shipping line but not with itself	0.25	0	1	Source: Shipping lines' websites
Control variables					
Shipping line specific (For 9 shipping lines)					
c_teu	Shipping line's capacity (TEU, thousands)	1,961	632	4,070	Source: Alphaliner. (2018)
c_fleet	Shipping line's total number of ships	333	100	737	Source: Alphaliner. (2018)
Route specific (For 421 routes)					
owdist	Route's one way distance	13,864	6,290	23,311	Summation of surface distances of sequential port of calls Source: Shipping lines' websites
owday	Route's one way voyage days	29	11	60	Source: Shipping lines' websites
owpoc	Route's one way port-of-calls	6	3	12	Source: Shipping lines' websites
ta_gdp	Target market's GDP in 2016 (USD, billions)	5,084	2	18,624	Summation of country GDPs of all non-East Asian ports. Source: the World Bank
Port specific (For 27 ports)					
vin2016	Container throughput in 2016 (TEU, thousands)	8,696	246	37,133	Source: terminal operators' and port authorities' websites
vin2017	Container throughput in 2017 (TEU, thousands)	9,212	246	40,233	Source: terminal operators' and port authorities' websites
sts	Number of ship-to-shore cranes	51	4	155	Source: terminal operators' and port authorities' websites
ht	Average handling time	755	504	1,080	Source: UNCTAD
Cluster specific (For 7 clusters)					
htldgdp16	Hinterland GDP in 2016 (USD, billions)	3,163	531	5,018	Source: the World Bank and the National Bureau of Statistics of China
htldgdp17	Hinterland GDP in 2017 (USD, billions)	3,354	579	5,470	Source: the World Bank and the National Bureau of Statistics of China
htldv16	Hinterland import/export volume in 2016 (USD, millions)	1,156	573	1,745	Source: the World Bank and the National Bureau of Statistics of China
htldv17	Hinterland import/export volume in 2017 (USD, millions)	1,319	508	1,968	Source: the World Bank and the National Bureau of Statistics of China
htldports	Number of hinterland ports	5	2	8	Source: Shipping lines' websites

Table 5 TETRACHORIC CORRELATION MATRIX OF PORT-OF-CALLS

	yantian	*shekou*	*nansha*	*hongkong*	*qingdao*	*dalian*	*xingang*	*shanghai*	*ningbo*	*lianyungang*	*xiamen*	*fuzhou*	*tokyo*	*kobe*	*yokohama*
yantian	1.0000														
shekou	-0.5077***	1.0000													
nansha	-0.1323	0.0904	1.0000												
hongkong	0.2642***	0.2758***	-0.0116	1.0000											
qingdao	-0.3826***	-0.1502*	0.1128	-0.1677**	1.0000										
dalian	-0.2771*	-0.2265	-0.1257	-1.0000***	0.0190	1.0000									
xingang	-0.1688	-0.3300***	0.0860	-0.4662***	0.5731***	0.7424***	1.0000								
shanghai	-0.2419***	0.1241	0.0529	-0.0161	0.3566***	0.1865	0.0523	1.0000							
ningbo	-0.2085**	0.2422***	-0.2866***	-0.0564	0.2323***	0.0099	-0.1084	0.5085***	1.0000						
lianyungang	-1.0000***	0.0664	0.4157**	0.1695	0.2152*	0.6630***	-0.0702	-0.2534	0.3484	1.0000					
xiamen	0.4564***	-0.0086	0.0906	0.0296	-0.5091***	-0.2810	-0.3154**	-0.1599*	-0.3113***	-1.0000*	1.0000				
fuzhou	0.0719	-0.0675	0.4982***	-1.0000*	-1.0000**	-1.0000	-1.0000	-0.5625***	-1.0000***	-1.0000	0.2414	1.0000			
tokyo	-0.0932	-0.6464***	-1.0000***	-0.3160**	-0.0078	-1.0000	-1.0000**	-0.2912**	-0.1997*	-1.0000	-0.4979***	-1.0000	1.0000		
kobe	-0.1763	-0.5870***	-1.0000**	-0.5074***	-0.3491**	-1.0000	-1.0000*	-0.4444***	-0.3747***	-1.0000	-1.0000***	-1.0000	0.9852***	1.0000	
yokohama	-0.1802	-0.2478**	-0.0719	-0.1263	0.3781***	-0.1426	-0.2070	0.3284**	0.0169	-1.0000	-0.0683	-1.0000	-1.0000*	-0.1631	1.0000
nagoya	-1.0000***	-0.4852***	-1.0000	-0.4018**	-0.1996	-1.0000	-1.0000	-0.5595***	-0.4614***	-1.0000	-1.0000**	-1.0000	0.9442***	1.0000***	-0.0523
osaka	-0.1128	-1.0000***	-1.0000	-0.1257	1.0000***	-1.0000	-1.0000	1.0000**	0.4050**	-1.0000	-1.0000**	-1.0000	0.4085**	-1.0000	0.7937***
hakata	-1.0000	-1.0000	-1.0000	-1.0000	1.0000	1.0000*	-1.0000	-1.0000	1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	1.0000*
shimizu	-1.0000*	-1.0000*	-1.0000	-1.0000	-1.0000*	-1.0000	-1.0000	-1.0000**	-1.0000***	-1.0000	-1.0000	-1.0000	1.0000***	1.0000***	-1.0000
sendai	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000**	-1.0000***	-1.0000	-1.0000	-1.0000	1.0000***	1.0000***	-1.0000
busan	-0.0156	0.1256	-0.3544***	-0.0372	0.3513***	0.0893	0.1538	0.5248***	0.0434	-0.4438**	-0.0345	-1.0000**	-0.2518**	-0.2369*	0.6308***
incheon	-1.0000	-1.0000	0.3678	-1.0000	1.0000	0.5588	1.0000**	1.0000	-0.1556	0.6686*	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000
kwangyang	-0.0839	0.1611	-0.1517	0.0947	0.2137	0.4195**	0.3978**	-0.1816	0.1235	-1.0000	-0.2913	-1.0000	-1.0000	-1.0000	0.4080**
ulsan	-1.0000	-1.0000	-1.0000	-1.0000	0.1333	0.5588	0.4023	1.0000	-1.0000	-1.0000	0.2457	-1.0000	-1.0000	-1.0000	-1.0000
kaohsiung	0.3136***	0.2963***	-0.4118***	0.2379***	-0.3412***	-1.0000***	-0.4097***	-0.4751***	-0.0971	-1.0000*	0.2573***	-1.0000	-0.0757	-0.1616	0.0813
taipei	0.2924**	0.3289**	-0.2653	-0.1738	-0.3079*	-1.0000	-0.2240	-0.0650	1.0000*	-1.0000	0.0725	-1.0000	-1.0000	-1.0000	-1.0000
keelung	0.2846*	-0.1823	-1.0000	0.4381***	-0.4584**	-1.0000	-1.0000	0.0852	0.1006	-1.0000	0.2583*	-1.0000	-1.0000	-1.0000	-0.0675

	nagoya	*osaka*	*hakata*	*shimizu*	*sendai*	*busan*	*incheon*	*kwangyang*	*ulsan*	*kaohsiung*	*taipei*	*keelung*
nagoya	1.0000											
osaka	-1.0000	1.0000										
hakata	-1.0000	-1.0000	1.0000									
shimizu	1.0000***	-1.0000	-1.0000	1.0000								
sendai	1.0000***	-1.0000	-1.0000	-1.0000	1.0000							
busan	-1.0000***	0.3241*	1.0000	-1.0000**	-1.000*	1.0000						
incheon	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	0.0628	1.0000					
kwangyang	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	0.6013***	-1.0000	1.0000				
ulsan	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	1.0000	-1.0000	0.6433*	1.0000			
kaohsiung	-0.3557	0.2838*	-1.0000	-1.0000	-1.0000	-0.2329***	-1.0000	0.2384	-1.0000	1.0000		
taipei	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000***	-1.0000	-1.0000	-1.0000	0.2210	1.0000	
keelung	-1.0000	-1.0000	-1.0000	-1.0000	-1.0000	-0.0623	-1.0000	-1.0000	-1.0000	0.1455	-1.0000	1.0000

* p<0.1, **p<0.05, ***p<0.01

Table 6 PROBIT REGRESSION MODELS WITH CLUSTER SPATIAL MATRICES

Variables	*Model 1a*	*Model 2a*	*Model 1b*	*Model 2b*	*Non-Asian*	*Asian*
Tests of target variables						
ownt			2.17E-01 ***	2.18E-01 ***	2.23E-01 *	2.40E-01 ***
alliancet			2.29E-01 ***	2.32E-01 ***	2.54E-01 ***	2.48E-01 ***
Test of spatial variable						
ρ	6.19E-02 ***	3.77E-02 **	6.21E-02 ***	3.67E-02 **	2.93E-02	3.92E-02 *
Control variables						
Shipping line specific variables						
c_teu	-1.58E-08	-5.78E-09	1.45E-07	1.33E-07	1.00E-07	3.00E-07
c_fleet	2.04E-04	1.50E-04	-6.19E-04	-5.68E-04	-3.55E-04	-1.69E-03
Route specific variables						
owdist	-8.67E-06	-9.53E-06	-7.72E-06	-8.81E-06	-2.20E-06	-1.07E-05
owday	-4.26E-03 *	-4.38E-03 *	-4.33E-03 **	-4.25E-03 *	-6.66E-03 *	-3.54E-03
owpoc	5.12E-02 ***	5.31E-02 ***	5.06E-02 ***	5.26E-02 ***	5.45E-02 ***	5.26E-02 ***
ta_gdp	4.07E-06	4.27E-06 ●	3.89E-06	4.33E-06 ●	2.36E-06	4.92E-06
Port specific variables						
vin2016	4.60E-04 ***	4.59E-04 ***	5.67E-04 ***	5.66E-04 ***	5.05E-04 ***	6.38E-04 ***
vin2017	-4.40E-04 ***	-4.38E-04 ***	-5.48E-04 ***	-5.46E-04 ***	-4.84E-04 ***	-6.19E-04 ***
sts	1.62E-02 ***	1.62E-02 ***	1.60E-02 ***	1.58E-02 ***	1.69E-02 ***	1.55E-02 ***
ht	-1.56E-03 ***	-1.64E-03 ***	-1.61E-03 ***	-1.62E-03 ***	-2.25E-03 ***	-1.18E-03 *
Cluster specific variables						
htldgdp16	-4.67E-04	-5.69E-04	-7.05E-04	-7.30E-04	-2.78E-03 *	6.23E-04
htldgdp17	5.07E-04	6.12E-04	7.10E-04	7.28E-04	2.55E-03 *	-4.70E-04
htldv16	5.82E-04	6.27E-04	6.59E-06	-4.03E-05	-1.63E-03 ●	9.48E-04
htldv17	3.51E-04	2.88E-04	1.10E-03 *	1.15E-03 *	2.59E-03 **	3.01E-04
htldports	-2.79E-01 ***	-2.72E-01 ***	-3.29E-01 ***	-3.27E-01 ***	-2.17E-01 ***	-4.12E-01 ***
_cons	-9.69E-01 ***	-9.70E-01 ***	-1.01E+00 ***	-1.04E+00 ***	-8.70E-01 ***	-1.20E+00 ***
McFadden's Pseudo R-Squared	0.282	0.283	0.286	0.287	0.287	0.292

"●" p<0.1 "*" p<0.05, "**" p<0.01, "***" p<0.001

Table 7 PROBIT REGRESSION MODELS WITH NEIGHBOURING RADIUS SPATIAL MATRICES

Variables	*<400*	*400-800*	*800-1200*	*1200-1600*	*1600-2000*	*2000-2400*	*>2400*
Tests of target variables							
ownt	2.19E-01 ***	2.10E-01 ***	2.09E-01 ***	2.11E-01 ***	2.10E-01 ***	2.15E-01 ***	2.10E-01 ***
alliancet	2.36E-01 ***	2.28E-01 ***	2.27E-01 ***	2.26E-01 ***	2.31E-01 ***	2.32E-01 ***	2.26E-01 ***
Test of spatial variable							
ρ	3.35E-02 **	4.26E-02 **	4.30E-02 **	-1.33E-02	-3.52E-02 *	-3.37E-02 *	-4.32E-02 *
Control variables							
Shipping line specific variables							
c_teu	1.40E-07	1.25E-07	1.31E-07	1.25E-07	1.48E-07	1.38E-07	1.31E-07
c_fleet	-5.91E-04	-5.24E-04	-5.60E-04	-5.22E-04	-6.31E-04	-5.81E-04	-5.53E-04
Route specific variables							
owdist	-7.58E-06	-7.17E-06	-8.48E-06	-8.26E-06	-7.28E-06	-7.94E-06	-8.07E-06
owday	-4.72E-03 **	-4.46E-03 **	-4.40E-03 *	-4.80E-03 **	-5.07E-03 **	-4.92E-03 **	-4.86E-03 **
owpoc	5.31E-02 ***	5.09E-02 ***	5.26E-02 ***	5.54E-02 ***	5.61E-02 ***	5.61E-02 ***	5.54E-02 ***
ta_gdp	4.20E-06 ●	3.75E-06	4.20E-06 ●	ta_gdp ●	4.41E-06 ●	4.41E-06 ●	4.21E-06 ●
Port specific variables							
vin2016	5.72E-04 ***	5.65E-04 ***	5.70E-04 ***	5.69E-04 ***	5.65E-04 ***	5.73E-04 ***	5.76E-04 ***
vin2017	-5.52E-04 ***	-5.44E-04 ***	-5.49E-04 ***	-5.49E-04 ***	-5.44E-04 ***	-5.54E-04 ***	-5.56E-04 ***
sts	1.60E-02 ***	1.58E-02 ***	1.58E-02 ***	1.58E-02 ***	1.58E-02 ***	1.61E-02 ***	1.58E-02 ***
ht	-1.61E-03 ***	-1.63E-03 ***	-1.62E-03 ***	-1.60E-03 ***	-1.60E-03 ***	-1.57E-03 ***	-1.60E-03 ***
Cluster specific variables							
htldgdp16	-7.53E-04	-7.70E-04	-6.83E-04	-7.78E-04	-6.82E-04	-6.73E-04	-6.87E-04
htldgdp17	7.50E-04	7.64E-04	6.86E-04	7.73E-04	6.85E-04	6.73E-04	6.84E-04
htldv16	-6.46E-05	-7.80E-05	-2.05E-06	-1.17E-04	-7.97E-06	-4.85E-05	-1.04E-04
htldv17	1.18E-03 *	1.19E-03 *	1.12E-03 *	1.22E-03 *	1.11E-03 *	1.18E-03 *	1.23E-03 *
htldports	-3.29E-01 ***	-3.26E-01 ***	-3.30E-01 ***	-3.28E-01 ***	-3.27E-01 ***	-3.35E-01 ***	-3.36E-01 ***
_cons	-1.06E+00 ***	-1.01E+00 ***	-1.02E+00 ***	-1.11E+00 ***	-1.16E+00 ***	-1.16E+00 ***	-1.10E+00 ***
McFadden's Pseudo R-Squared	0.287	0.287	0.287	0.286	0.287	0.288	0.287

"●" p<0.1 "*" p<0.05, "**" p<0.01, "***" p<0.001

Appendices

Appendix A

The below examples illustrate how shipping routes are stored and recorded.

route_id	*carrier*	*alliance*	*route*	*port*	*portcluster*	*poc*	*ownt*	*alliancet*	*vin2016*	*vin2017*	*sts*	*htldgdp16*	*htldgdp17*	*htldv16*	*htldv17*	*htldports*	*c_teu*	*c_fleet*	*owdist*	*owday*	*owpoc*	*ta_gdp*	*lgta_gdp*	*ht*
1	Maersk	2M	TP5	Yantian	SC	0	0	0	13021	14027	111	3,832.22	4,139.00	1,745.33	1,900.41	6	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Shekou	SC	0	0	0	10958	11181	70	3,832.22	4,139.00	1,745.33	1,900.41	6	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Nansha	SC	0	1	0	18859	20370	63	3,832.22	4,139.00	1,745.33	1,900.41	6	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Hong Kong	SC	0	0	0	19813	20770	99	3,832.22	4,139.00	1,745.33	1,900.41	6	4069566	737	10168	14	3	18,624.50	30.56	1,080.00
1	Maersk	2M	TP5	Qingdao	NC	0	1	0	18010	18262	80	3,246.21	3,538.00	725.30	817.84	4	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Dalian	NC	0	0	0	9614	9707	35	3,246.21	3,538.00	725.30	817.84	4	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Xingang	NC	0	1	0	14490	15040	79	3,246.21	3,538.00	725.30	817.84	4	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Shanghai	EC	0	1	0	37133	40233	155	5,017.90	5,470.00	1,585.23	1,796.57	2	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Ningbo	EC	0	0	1	21560	24607	102	5,017.90	5,470.00	1,585.23	1,796.57	2	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Lianyungang	NC	0	0	0	4703	4710	23	3,246.21	3,538.00	725.30	817.84	4	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Xiamen	SC	0	1	0	9614	10380	75	3,832.22	4,139.00	1,745.33	1,900.41	6	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Fuzhou	SC	0	0	0	2650	3007	22	3,832.22	4,139.00	1,745.33	1,900.41	6	4069566	737	10168	14	3	18,624.50	30.56	892.80
1	Maersk	2M	TP5	Tokyo	JAP	0	0	0	4250	4500	73	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Kobe	JAP	0	1	0	2801	2924	28	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Yokohama	JAP	0	1	0	2658	2926	32	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Nagoya	JAP	0	0	0	2658	2784	28	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Osaka	JAP	0	0	0	2216	2326	20	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Hakata	JAP	0	0	0	897	920	9	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Shimizu	JAP	0	0	0	541	571	5	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Sendai	JAP	0	0	0	246	260	4	4,939.00	4,872.00	1,251.86	1,699.57	8	4069566	737	10168	14	3	18,624.50	30.56	504.00
1	Maersk	2M	TP5	Busan	KOR	1	0	0	19456	20493	114	1,411.00	1,531.00	901.60	1,052.10	4	4069566	737	10168	14	3	18,624.50	30.56	864.00
1	Maersk	2M	TP5	Incheon	KOR	0	0	0	2679	3050	23	1,411.00	1,531.00	901.60	1,052.10	4	4069566	737	10168	14	3	18,624.50	30.56	864.00
1	Maersk	2M	TP5	Kwangyang	KOR	0	0	0	2224	2230	21	1,411.00	1,531.00	901.60	1,052.10	4	4069566	737	10168	14	3	18,624.50	30.56	864.00
1	Maersk	2M	TP5	Ulsan	KOR	0	0	0	423	217	5	1,411.00	1,531.00	901.60	1,052.10	4	4069566	737	10168	14	3	18,624.50	30.56	864.00
1	Maersk	2M	TP5	Kaohsiung	TW	0	0	0	10464	10271	66	531.00	579.00	572.74	508.42	3	4069566	737	10168	14	3	18,624.50	30.56	662.40
1	Maersk	2M	TP5	Taipei	TW	0	0	0	1477	1561	13	531.00	579.00	572.74	508.42	3	4069566	737	10168	14	3	18,624.50	30.56	662.40
1	Maersk	2M	TP5	Keelung	TW	0	0	0	1388	1418	30	531.00	579.00	572.74	508.42	3	4069566	737	10168	14	3	18,624.50	30.56	662.40
2	CMACGM	OCEAN	China India Middle East Express 2N	Yantian	SC	0	0	1	13021	14027	111	3,832.22	4,139.00	1,745.33	1,900.41	6	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Shekou	SC	0	0	0	10958	11181	70	3,832.22	4,139.00	1,745.33	1,900.41	6	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Nansha	SC	0	0	1	18859	20370	63	3,832.22	4,139.00	1,745.33	1,900.41	6	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Hong Kong	SC	0	0	1	19813	20770	99	3,832.22	4,139.00	1,745.33	1,900.41	6	2623451	511	9677	49	13	81.32	25.12	1,080.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Qingdao	NC	1	0	1	18010	18262	80	3,246.21	3,538.00	725.30	817.84	4	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Dalian	NC	1	0	1	9614	9707	35	3,246.21	3,538.00	725.30	817.84	4	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Xingang	NC	1	0	1	14490	15040	79	3,246.21	3,538.00	725.30	817.84	4	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Shanghai	EC	0	0	1	37133	40233	155	5,017.90	5,470.00	1,585.23	1,796.57	2	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Ningbo	EC	1	0	1	21560	24607	102	5,017.90	5,470.00	1,585.23	1,796.57	2	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Lianyungang	NC	0	0	1	4703	4710	23	3,246.21	3,538.00	725.30	817.84	4	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Xiamen	SC	0	1	0	9614	10380	75	3,832.22	4,139.00	1,745.33	1,900.41	6	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Fuzhou	SC	0	0	0	2650	3007	22	3,832.22	4,139.00	1,745.33	1,900.41	6	2623451	511	9677	49	13	81.32	25.12	892.80
2	CMACGM	OCEAN	China India Middle East Express 2N	Tokyo	JAP	0	0	0	4250	4500	73	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Kobe	JAP	0	0	0	2801	2924	28	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Yokohama	JAP	0	0	0	2658	2926	32	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Nagoya	JAP	0	0	0	2658	2784	28	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Osaka	JAP	0	0	0	2216	2326	20	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Hakata	JAP	0	0	0	897	920	9	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Shimizu	JAP	0	0	0	541	571	5	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Sendai	JAP	0	0	0	246	260	4	4,939.00	4,872.00	1,251.86	1,699.57	8	2623451	511	9677	49	13	81.32	25.12	504.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Busan	KOR	1	1	0	19456	20493	114	1,411.00	1,531.00	901.60	1,052.10	4	2623451	511	9677	49	13	81.32	25.12	864.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Incheon	KOR	0	0	0	2679	3050	23	1,411.00	1,531.00	901.60	1,052.10	4	2623451	511	9677	49	13	81.32	25.12	864.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Kwangyang	KOR	1	0	0	2224	2230	21	1,411.00	1,531.00	901.60	1,052.10	4	2623451	511	9677	49	13	81.32	25.12	864.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Ulsan	KOR	0	0	0	423	217	5	1,411.00	1,531.00	901.60	1,052.10	4	2623451	511	9677	49	13	81.32	25.12	864.00
2	CMACGM	OCEAN	China India Middle East Express 2N	Kaohsiung	TW	0	0	1	10464	10271	66	531.00	579.00	572.74	508.42	3	2623451	511	9677	49	13	81.32	25.12	662.40
2	CMACGM	OCEAN	China India Middle East Express 2N	Taipei	TW	0	0	1	1477	1561	13	531.00	579.00	572.74	508.42	3	2623451	511	9677	49	13	81.32	25.12	662.40
2	CMACGM	OCEAN	China India Middle East Express 2N	Keelung	TW	0	0	0	1388	1418	30	531.00	579.00	572.74	508.42	3	2623451	511	9677	49	13	81.32	25.12	662.40

Appendix B

The spatial matrix W^{cb} is a block matrix, with matrix A^{cb} on its main diagonal. In total there are 421 matrices A^{cb}, for all the collected routes. And A^{cb} is a 27×27 matrix. Entry A_{ij}^{cb} depicts if port i and j $(i \neq j)$ are considered to be in the port cluster (=1) or not (=0). More specifically, W^{cb} is defined as follows:

$$W^{cb} = \begin{bmatrix} A^{cb} & 0 & \dots & 0 \\ 0 & A^{cb} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \dots & 0 & A^{cb} \end{bmatrix}, \text{ where } A^{cb} =$$

	Yantian	Shekou	Nansha	Hong Kong	Qingdao	Dalian	Xingang	Shanghai	Ningbo	Lianyungang	Xiamen	Fuzhou	Tokyo	Kobe	Yokohama	Nagoya	Osaka	Hakata	Shimizu	Sendai	Busan	Incheon	Kwangyang	Ulsan	Kaohsiung	Taipei	Keelung
Yantian	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shekou	1	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nansha	1	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hong Kon	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Qingdao	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dalian	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Xingang	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shanghai	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ningbo	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lianyunga	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiamen	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fuzhou	1	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tokyo	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Kobe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0
Yokoham	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0
Nagoya	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0
Osaka	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0
Hakata	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	0	0	0	0	0	0	0
Shimizu	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0
Sendai	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Busan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
Incheon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0
Kwangyan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0
Ulsan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
Kaohsiun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Taipei	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Keelung	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0

Similarly, the spatial matrix W^{cd} consists of 421 identical 27×27 matrices A^{cd}. A_{ij}^{cd} is defined as the standardized distance inverse if port i and j $(i \neq j)$ are considered to be in the port cluster, and 0 otherwise. The specific structure of W^{cd} is defined as follows:

$$W^{cd} = \begin{bmatrix} A^{cd} & 0 & \dots & 0 \\ 0 & A^{cd} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \dots & 0 & A^{cd} \end{bmatrix}, \text{ where } A^{cd} =$$

	Yantian	Shekou	Nansha	Hong Kong	Qingdao	Dalian	Xingang	Shanghai	Ningbo	Lianyungang	Xiamen	Fuzhou	Tokyo	Kobe	Yokohama	Nagoya	Osaka	Hakata	Shimizu	Sendai	Busan	Incheon	Kwangyang	Ulsan	Kaohsiung	Taipei	Keelung
Yantian	0	0.341	0.163	0.445	0	0	0	0	0	0	0.03	0.021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shekou	0.297	0	0.213	0.449	0	0	0	0	0	0	0.024	0.017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nansha	0.263	0.395	0	0.268	0	0	0	0	0	0	0.043	0.031	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hong Kong	0.379	0.439	0.142	0	0	0	0	0	0	0	0.024	0.017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Qingdao	0	0	0	0	0	0.281	0.236	0	0	0.483	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dalian	0	0	0	0	0.379	0	0.379	0	0	0.242	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Xingang	0	0	0	0	0.335	0.4	0	0	0	0.265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shanghai	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ningbo	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lianyungang	0	0	0	0	0.57	0.211	0.219	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiamen	0.172	0.159	0.152	0.163	0	0	0	0	0	0	0	0.355	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fuzhou	0.147	0.139	0.137	0.141	0	0	0	0	0	0	0.437	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tokyo	0	0	0	0	0	0	0	0	0	0	0	0	0	0.042	0.635	0.068	0.044	0.02	0.133	0.058	0	0	0	0	0	0	0
Kobe	0	0	0	0	0	0	0	0	0	0	0	0	0.044	0	0.045	0.113	0.666	0.041	0.062	0.029	0	0	0	0	0	0	0
Yokohama	0	0	0	0	0	0	0	0	0	0	0	0	0.622	0.042	0	0.069	0.045	0.02	0.151	0.052	0	0	0	0	0	0	0
Nagoya	0	0	0	0	0	0	0	0	0	0	0	0	0.122	0.191	0.127	0	0.227	0.051	0.218	0.064	0	0	0	0	0	0	0
Osaka	0	0	0	0	0	0	0	0	0	0	0	0	0.046	0.645	0.047	0.13	0	0.037	0.066	0.029	0	0	0	0	0	0	0
Hakata	0	0	0	0	0	0	0	0	0	0	0	0	0.109	0.211	0.111	0.155	0.199	0	0.127	0.089	0	0	0	0	0	0	0
Shimizu	0	0	0	0	0	0	0	0	0	0	0	0	0.224	0.098	0.258	0.204	0.108	0.039	0	0.071	0	0	0	0	0	0	0
Sendai	0	0	0	0	0	0	0	0	0	0	0	0	0.222	0.105	0.203	0.137	0.109	0.063	0.161	0	0	0	0	0	0	0	0
Busan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.092	0.237	0.671	0	0	0
Incheon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.315	0	0.355	0.33	0	0	0
Kwangyang	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.448	0.196	0	0.357	0	0	0
Ulsan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.702	0.101	0.197	0	0	0	0
Kaohsiung	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.514	0.486
Taipei	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.064	0	0.936
Keelung	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.061	0.939	0