The effect of distance on cargo flows: a case study of Chinese imports and their hinterland destinations

Article *in* Maritime Economics & Logistics · May 2017

DOI: 10.1057/s41278-017-0079-3

Likun Wang
Shanghai Maritime University

Anne Goodchild
University of Washington Seattle

Yong Wang
Chongqing Jiaotong University

Marit Econ Logist
DOI 10.1057/s41278-017-0079-3

ORIGINAL ARTICLE

The effect of distance on cargo flows: a case study of Chinese imports and their hinterland destinations

Likun Wang[1] · **Anne Goodchild**[2] · **Yong Wang**[3]

Abstract With the rapid development of ports in China, competition for cargo is growing. The ability of a port to attract hinterland traffic is affected by many factors, including distance to the hinterland destinations. This paper studies the effects of distance on import cargo flows from a port to its hinterland. Two major findings are reported. Through a *Spatial Concentration Analysis*, this study shows that cargo imported through ports with relatively low throughput is primarily delivered to local areas, with the proportion of cargo delivered to local areas from larger ports being much smaller. The present study also shows (according to a gravity model, the Gompertz function and several other methods) that cargo flows from a large port to its hinterland increase with distance below a certain threshold, while cargo flows approach a stable state once they exceed this threshold. These results can be used to inform port managers and policy makers regarding the hinterland markets for ports of different sizes.

Keywords Import cargo flow · Hinterland · Ports of China · Distance decay · Gompertz model

✉ Likun Wang
lkwang@shmtu.edu.cn

[1] College of Transport and Communications, Shanghai Maritime University, Shanghai 201306, People's Republic of China

[2] Department of Civil and Environmental Engineering, University of Washington, 121E More Hall, Seattle, WA 98195, USA

[3] School of Economics and Management, Chongqing Jiaotong University, Chongqing 400074, People's Republic of China

Introduction

Over the past two decades, sea ports in China have developed quickly. For example, the number of productive berths of deep-sea ports increased from 967 to 5675 from 1990 to 2013, of which the number of million-ton berths increased from 284 to 1607 (China port yearbook). As importers for a particular destination can choose which port to use as an import location, this growth has presented challenges for ports in terms of attracting traffic to hinterlands.

A hinterland in this study is defined as the land area surrounding an import destination and from which exports are collected. Its overseas equivalent, foreland, is defined as an area from which cargo originates (Ferrari et al. 2011). Distance decay is a well-established phenomenon of passenger transportation (Fotheringham 1981; Luoma et al. 1993). The concept has also been explored in reference to freight transportation, in which hinterland shippers or consignees typically select the closest ports to import/export cargo. Such selection has been attributed to cost minimization. The cost of hinterland transport accounts on average for approximately 40% of all container transportation costs (Notteboom and Winkelmans 2001). It has been shown that in the US (Levine et al. 2009; Jones et al. 2011) and France (Guerrero 2014), cargo volumes decrease with distance.

This paper investigates whether the same phenomenon can be observed for imports in China, and it describes the nature of this relationship.

Literature review

Shippers have been shown to choose the least costly route from an origin to a destination (Luo and Grigalunas 2003), and inland transportation costs seem to affect port choice (Blonigen and Wilson 2006). Hinterland rail capacity is known to be more restrictive than port handling capacity for container flows destined for US markets (Fan et al. 2010), and assuming that shippers tend to minimize total logistics costs, hinterland rail disruptions change port selection outcomes (Jones et al. 2011). Large shippers in the US emphasize factors that affect the speed of delivery more than they emphasize freight charges, unlike smaller shippers, and inland transit times appear to affect port choice (Tiwari et al. 2003; Steven and Corsi 2012). Statistically, inland distances have been shown to significantly affect port choice (Malchow and Kanafani 2004); US domestic haulage cargo imported from Asia has been forecasted to increase with improvements to inland infrastructure (Leachman 2008); hinterland cargo flows typically exhibit distance decay in French and Ligurian ports (Guerrero 2014; Ferrari et al. 2011).

From the above papers, inland transportation times, distances, and prices are known to be key factors influencing port choice, and these three elements are positively correlated. Transportation price data are typically more difficult to obtain than distance and time data, while time data are subject to more variability due to varying road and traffic conditions. This paper only discusses the relationship between cargo flows and inland distances for ports in China.

Levine et al. (2009) forecast hinterland cargo flows using the gravity model and using data from the US Maritime Administration and US Department of Commerce. US PIERS can provide information on every bill of lading, allowing for the application of a discrete choice model to analyze the relationship between hinterland cargo flows and distance (Malchow and Kanafani 2004). Hinterland cargo flow data were also obtained from survey data drawn from various studies as is shown in Table 1. In China, aggregated cargo flows of all consignments between ports and delivery locations are available.

Data sources and data processing

The raw data on port-hinterland cargo flows obtained from the China Customs information center include values, weights, origins, and destinations of China imports sent from 295 import customs offices to 743 destination areas in 2012.

Creating port and hinterland data

For the raw data, the origins of port-hinterland cargo flows are given as customs offices, which are found at terminals or sub-ports (hereinafter referred to as terminals) that are open to foreign trade. Of the top 63 ports in China, each port has one or more terminals with 115 terminals in total. Figure 1 shows data consolidation structures from the customs level to the port level; *m*, *h,* and *i* are indices for customs offices, terminals, and ports, respectively.

In this paper, we discuss port destination hinterlands and refer to hinterlands on two scales: destination provinces and destination areas, indexed as *k* and *j*, respectively.

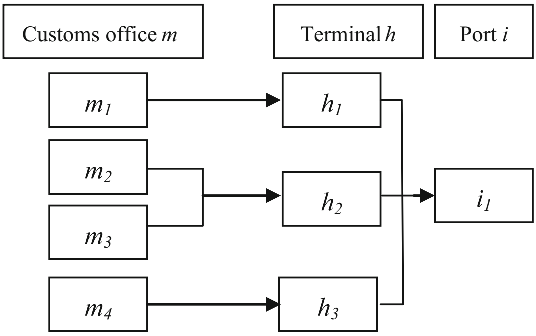
Cargo flow data

The raw cargo flow data cover the inland section from customs office *m* to destination area *j* as indexed by v_{mj}^{CI}. Here, v_{ij}^{PI} and v_{ik}^{PR} represent cargo flows from port *i* to destination area *j* and cargo flows from port *i* to destination province *k,* respectively. D_j^I, D_k^R, and O_i^P represent the gross import cargo volume of destination area *j*, the gross import cargo volume of destination province *k*, and the gross import

Table 1 Sources of cargo flow data

Data sources	Relating papers
Foreign trade statistics bureau	Levine et al. (2009), Ferrari et al. (2011), Guerrero (2014)
Port import export reporting service (PIERS) database	Luo and Grigalunas (2003), Malchow and Kanafani (2004), Leachman (2008), Jones et al. (2011), Steven and Corsi (2012)
Survey	Tiwari et al. (2003), Tongzon and Heng (2005), De Langen (2007), Chang et al. (2008), Yuen et al. (2012)

Fig. 1 Data consolidation from the customs level to the port level



cargo volume of port *i*, respectively ($m \in$ {all customs offices serving port i}, $j \in$ {all areas of province k}).

$$v_{ij}^{PI} = \sum_m v_{mj}^{CI} \tag{1}$$

$$v_{ik}^{PR} = \sum_j v_{ij}^{PI} \tag{2}$$

$$D_j^I = \sum_i v_{ij}^{PI} \tag{3}$$

$$D_k^R = \sum_i v_{ik}^{PR} \tag{4}$$

$$O_i^P = \sum_j v_{ij}^{PI} \tag{5}$$

The import cargo flow is in this paper given as the amount or value in kilograms or dollars; Guerrero (2014) believes that weight and value have little influence on the destination distribution analysis of import cargo.

Distance data

Cargo sent between ports and destinations is primarily transported by road. Monios and Wang (2013) found that 90% of inland freight transportation involves road transportation. In China, 85% of the throughput of the Shanghai port is collected and distributed by road (Shanghai port yearbook); this proportion is 75% for the Shenzhen port (Shenzhen port yearbook). In this paper, the distance between a port and delivery location is calculated as the length of the shortest driving path by road, which is more reasonable than the Euclidean distance. We set d_{ij}^{PI} and d_{mj}^{CI} as the distance from import port i to destination area j and as the distance from import customs office m to destination area j, respectively. Our analysis is conducted through the following steps:

Step 1: If the delivery destination area j is a metropolitan area, identify the geometric center; if the destination area j is an economic zone, identify the coordinates of the location

Step 2: Using Google Maps, Ports.com, and information drawn from port websites, obtain the coordinates of major terminals in China; when cargo handled by customs office m originates only from terminal h, customs office m is assumed to have the same coordinates as terminal h; if cargo handled by customs office m originates from several terminals, the coordinates of customs office m are calculated as the average coordinates of all terminals associated with customs office m

Step 3: Calculate the distance d_{mj}^{CI} using the shortest road driving distance; here $m \in \{\text{all customs serving port } i\}$. d_{ij}^{PI} is calculated from the following function

$$d_{ij}^{PI} = \frac{\sum v_{mj}^{CI} \cdot d_{mj}^{CI}}{\sum v_{mj}^{CI}}. \tag{6}$$

From these three steps, three matrices are created: a 31 (i.e., destination provinces) by 63 (i.e., ports) matrix for cargo flows measured in annual US dollars, a 743 (i.e., destination areas) by 63 (i.e., ports) matrix for cargo flows measured in annual US dollars and a 743 by 63 matrix for the shortest road driving distances measured in meters

Methodology

Spatial concentration analysis

Classic concentration/decentralization metrics include the Hirschman–Herfindahl index (HHI) (Herfindahl 1950) and the location quotient (LQ) (Hoare 1986). These have been used to analyze air traffic patterns (Reynolds-Feighanm 1998), the concentrations of European container ports (Notteboom 1997), and bulk ports along the west coast of Korea (Lee et al. 2014). Concentration and decentralization have been observed in warehousing and trucking activities carried out in US metropolitan areas using the Gini index (Cidell 2010). Notteboom (2006) studied spatial concentrations of container port systems in Europe and North America using the Gini index and Lorenz concentration curve.

This paper focuses on the spatial concentration/decentralization patterns of hinterlands of ports in China. Here, the province is used as the spatial unit for hinterlands. We analyze data on import cargo flows from each port to hinterland destinations. Four indices ($p_i^{A_u}$, HP_i, LP_{ik}, and r_i) have been calculated as described below to quantify spatial concentrations.

$$p_i^{A_1} = \frac{\sum\limits_{k \in A_1} v_{ik}^{PR}}{\sum\limits_k v_{ik}^{PR}} \quad p_i^{A_2} = \frac{\sum\limits_{k \in A_2} v_{ik}^{PR}}{\sum\limits_k v_{ik}^{PR}} \tag{7}$$

Ratio indicators $p_i^{A_1}$ and $p_i^{A_2}$ are the proportions of import cargo from port i to two sets of destination provinces A_1 and A_2, where A_1 is the local province where port i is located and where A_2 denotes provinces adjacent to A_1. When the unloaded cargo of a port is delivered to local or adjacent provinces, we consider the port to have a concentrated hinterland, which is here set as $p_i^{A_1} + p_i^{A_2} \geq 0.99$; when this is not the case, we consider the port's hinterland to be decentralized.

$$HP_i = \sum_k \left[\frac{v_{ik}^{PR}}{\sum\limits_k v_{ik}^{PR}} \right]^2, \tag{8}$$

where HP_i represents the HHI index of the hinterland of each port i. As the value of HP_i increases, the concentration of the port hinterland also increases.

$$LP_{ik} = \frac{v_{ik}^{PR} \Big/ \sum\limits_i v_{ik}^{PR}}{\sum\limits_k v_{ik}^{PR} \Big/ \sum\limits_i \sum\limits_k v_{ik}^{PR}}, \tag{9}$$

where LP_{ik} is the LQ index of the hinterland of each port i. When $LP_{ik} \geq 1$, the majority of cargo from port i is sent to destination province k, and province k can be defined as a core hinterland of port i. The larger the number of core destination provinces of port i, the more decentralized the hinterland of port i becomes.

$$r_i = \frac{\sum\limits_{k \in A_1} v_{ik}^{PR}}{\sum\limits_{k \in A_1} D_k^R} \tag{10}$$

Another ratio indicator r_i refers to the proportion of import cargo of port i of the total volume of import cargo of the port's local province. r_i denotes the capacity for each port i to attract local provincial cargo.

Distance–decay analysis

Distances and cargo flows

The concept of distance decay was first used in urban and economic geography (Fotheringham 1981). Previous work has shown that Newton's gravity model can be used to analyze relationships between distance and traffic flows (Wilson 1967; Ferrari et al. 2011; Guerrero 2014). This model is used in this paper to analyze the spatial relationship between cargo flows and distance, where distance is the only variable used; this model is thus a pure distance attenuation model, where λ is a constant, α is the distance–decay parameter, and all other parameters and variables have the same meanings as described above.

$$v_{ij}^{PI} = \lambda \cdot O_i^P \cdot D_j^I \cdot \left(d_{ij}^{PI}\right)^{\alpha} \tag{11}$$

Distances and cumulative cargo flows

For a given port i, distances d_{ij}^{PI} are sorted from small to large, yielding a new distance sequence that is equal to $x_{i1}, x_{i2},\ldots x_{iu},\ldots$; accordingly, a new cargo flow sequence is obtained as $q_{i1}, q_{i2},\ldots q_{iu},\ldots$ from v_{ij}^{PI}. We then define y_{iu} as the cumulative cargo flow from q_{i1} to q_{iu}.

Data for the Shanghai port are here used as an example. From the scatter diagram shown in Fig. 2, we can see that the relationship between the distance d_{ij}^{PI} and cargo flow v_{ij}^{PI} is not significant, while the relationship between the distance x_{iu} and the import cargo cumulative volume delivered from the port to the destination y_{iu} follows the Gompertz growth curve and S curve. Therefore, the Gompertz, S, Logistic, and Logarithmic models are used to verify whether port-hinterland cargo flows present similar growth rates along the curve. Moreover, some widely used functions such as the power, exponential, and Tanner functions are used to model the distance–decay relationships of transportation demand (Martínez and Viegas 2013).

Table 2 shows the functions used hereinafter to model the spatial effects of distance on the cumulative cargo volume. In the table below, β_0, β_1, and β_2 are constant parameters.

The standard SPSS Ver. 15.0 package was used; the "curve estimation" and "nonlinear regression" SPSS tools were used to fit the functions in Table 2 directly.

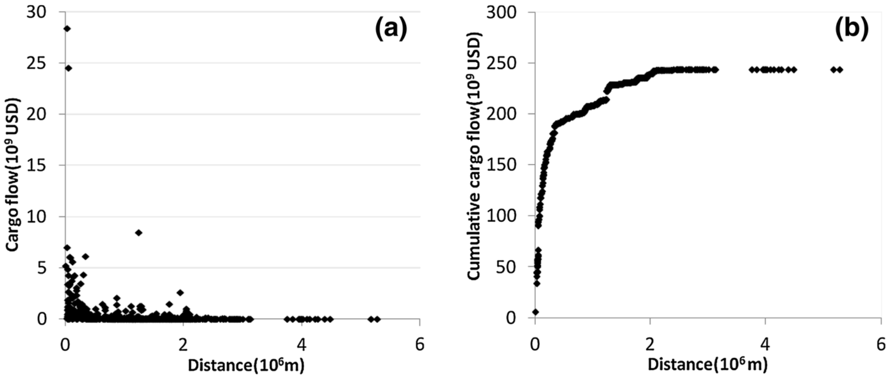


Fig. 2 Shanghai port cargo flow plot. **a** Cargo flow versus distance **b** Cumulative cargo flow versus distance

Table 2 Functions

Function	Basic form
Gompertz	$y_{iu} = \beta_0 \exp[-\beta_1 \exp(-\beta_2 x_{iu})]$
S	$y_{iu} = \exp(\beta_0 + \beta_1 / x_{iu})$
Logistic	$y_{iu} = \beta_0 + \beta_1 \ln(x_{iu})$
Logarithmic	$y_{iu} = \beta_0 + \beta_1 \ln(x_{iu})$
Power	$y_{iu} = \beta_0 x_u^{\beta_1}$
Exponential	$y_{iu} = \beta_0 e^{\beta_1 x_{iu}}$
Tanner	$y_{iu} = x^{\beta_0} e^{\beta_2 x_{iu}}$

Results

Spatial concentration analysis results

We conducted a spatial concentration analysis of the top 63 Chinese ports to identify the distance–decay phenomenon for port-hinterland cargo flows. Table 3 shows that cargo discharged at a port is distributed primarily to the province in which a port is located: approximately 28% of the 63 ports distribute nearly all imported cargo to local provinces; furthermore, 65% of the ports deliver 90% of imported cargo to local provinces. The calculation results of HP_i are consistent with $p_i^{A_1}$ and $p_i^{A_2}$.

Based on the results shown in Table 3, ports can be classified as those that exhibit spatial concentration or spatial decentralization. Moreover, the top 63 ports are categorized into four groups from small to large. Ports of the first category, for which throughputs are less than ten million tons, are marked with red circles in Fig. 3; ports of the second category, with throughputs between 10 and 50 million tons, are marked with blue circles in Fig. 4; ports of the third category, with throughputs of between 50 million tons and 100 million tons, are marked with purple circles in Fig. 4; and ports of the fourth category, with throughputs of more than 100 million tons, are marked with green circles in Figs. 5, 6, and 7. This is described in detail below.

Spatial concentrations

Ports of the first category, which belong to the high spatial concentration classification, are characterized by high $p_i^{A_1}$ and low r_i values. For each port of this category, more than 99% of imported cargo is distributed to the local province, whereas the volume of unloaded cargo for each port of this category covers only 8% of the total imported cargo for the local province on average.

Most ports of the second and third category belong to the spatial concentration classification, with high $p_i^{A_1} + p_i^{A_2}$ values and low r_i values. With the exception of the ports of Dongguan and Weihai, on average, more than 99% of the import cargo of ports in the second category is distributed to local and adjacent provinces;

Table 3 Spatial concentrations for port-hinterland cargo flows. *Source* Calculations were made by the author using Chinese customs import data for 2012 (USD)

Province	Port	$p_i^{A_1}$	$p_i^{A_2}$	HP_i	r_i
Northern China					
Liao Ning	Dalian	0.78	0.18	0.63	0.75
	Yingkou	0.93	0.06	0.86	0.18
	Jinzhou	0.68	0.32	0.56	0.03
	Dandong	0.87	0.13	0.77	0.02
Tianjin	Tianjin	0.43	0.42	0.29	0.92
Hebei	Tangshan	0.88	0.12	0.77	0.61
	Qinhuangdao	0.63	0.36	0.44	0.04
	Huanghua	0.98	0.01	0.97	0.01
Shandong	Qingdao	0.85	0.07	0.72	0.57
	Rizhao	0.88	0.07	0.77	0.23
	Yantai	0.93	0.04	0.86	0.11
	Weihai	0.39	0.22	0.26	0.04
	Weifang	1.00	0.00	1.00	0.00
Central China					
Shanghai	Shanghai	0.45	0.34	0.29	0.81
Jiangsu	Lianyungang	0.70	0.03	0.50	0.10
	Nantong	0.65	0.24	0.48	0.05
	Taicang	0.80	0.07	0.64	0.06
	Zhangjiagang	0.98	0.01	0.97	0.09
	Zhenjiang	0.93	0.03	0.87	0.03
	Jiangyin	0.95	0.03	0.90	0.05
	Taizhou	0.92	0.02	0.85	0.03
	Nanjing	0.48	0.17	0.32	0.02
	Changshu	0.65	0.19	0.45	0.01
	Changzhou	0.94	0.04	0.89	0.01
	Yangzhou	0.98	0.01	0.95	0.01
	Yancheng	0.95	0.00	0.91	0.00
Zhejiang	Ningbo	0.78	0.19	0.62	0.65
	Zhoushan	0.22	0.74	0.32	0.07
	Jiaxing	0.91	0.09	0.83	0.03
	Wenzhou	0.99	0.01	0.99	0.01
	Taizhou	1.00	0.00	1.00	0.02
Anhui	Wuhu	0.98	0.01	0.96	0.01
Hubei	Wuhan	1.00	0.00	1.00	0.00
	Jingzhou	1.00	0.00	1.00	0.00

Table 3 continued

Province	Port	$p_i^{A_1}$	$p_i^{A_2}$	HP_i	r_i
Chongqing	Chongqing	0.00	0.99	0.69	0.00
Southern China					
Fujian	Fuzhou	0.93	0.02	0.86	0.15
	Xiamen	0.92	0.07	0.84	0.45
	Quanzhou	1.00	0.00	1.00	0.25
	Zhangzhou	1.00	0.00	1.00	0.04
	Ningde	1.00	0.00	1.00	0.01
	Putian	1.00	0.00	1.00	0.03
Shenzhen	Shenzhen	0.93	0.02	0.86	0.12
Guangdong	Guangzhou	0.84	0.06	0.71	0.28
	Dongguan	0.34	0.02	0.31	0.04
	Zhanjiang	0.66	0.24	0.49	0.12
	Zhuhai	0.99	0.00	0.99	0.09
	Huizhou	1.00	0.00	1.00	0.11
	Zhongshan	1.00	0.00	1.00	0.04
	Foshan	0.99	0.00	0.98	0.09
	Yangjiang	0.99	0.00	0.99	0.01
	Jiangmen	1.00	0.00	0.99	0.03
	Shantou	1.00	0.00	0.99	0.01
	Zhaoqing	1.00	0.00	1.00	0.02
	Yunfu	1.00	0.00	1.00	0.00
Guangxi	Fangcheng	0.77	0.21	0.62	0.31
	Beihai	0.78	0.21	0.63	0.04
	Qinzhou	0.99	0.00	0.98	0.37
	Wuzhou	0.99	0.01	0.98	0.03
	Guigang	1.00	0.00	1.00	0.01
Hainan	Yangpu	1.00	0.00	0.99	0.84
	Haikou	1.00	0.00	1.00	0.09
	Basuo	1.00	0.00	1.00	0.03
	Sanya	0.98	0.02	0.97	0.01

however, imports from such ports only account for 16% of local province imports. For ports in the third category, these percentages are 96 and 19%, respectively.

In terms of the geographic distribution of the ports, ports in southern China tend to have more highly concentrated hinterlands; more than half of the ports in Fujian Province, Guangdong Province, Guangxi Province, and Hainan Province distribute over 99% of their unloaded cargo to local provinces. In terms of location, ports along the Xijiang River and along the upper and middle sections of the Yangtze River have more concentrated hinterlands.

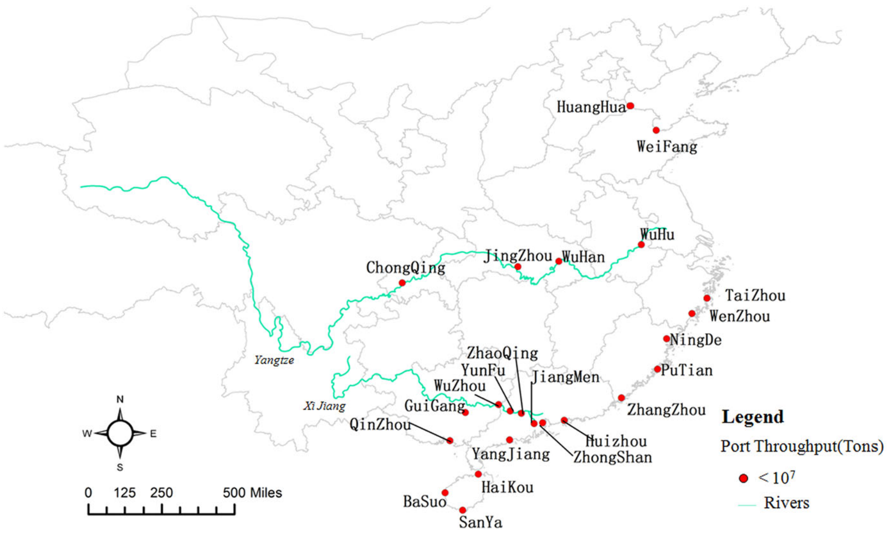


Fig. 3 Cargo flows from ports to destinations in China characterized by spatial centralization

Such results in terms of hinterland concentration may be due to the fact that shorter delivery distances can reduce transportation costs as well as risks resulting from long transit times.

The $p_i^{A_1} + p_i^{A_2}$ values of the Dongguan and Weihai ports are not as high as was expected for secondary category ports. Further research shows that the ratios of some high-value commodities delivered to non-local destinations from these two ports are relatively high. For the port of Weihai, the ratio is 42.04%, and the imported commodities belong to the harmonized system code (HS) 90 category, which includes optical, photoelectric, cinematographic, measuring, checking, precision, medical or surgical instruments, and accessories. For the port of Dongguan, the ratio is 62%, and commodities belong to the HS 87 category, which includes vehicles other than railway and tramway rolling stock.

Spatial decentralization

Top large ports

For ports of the fourth category, the port hinterland extends farther, while imports still focus on shorter-distance deliveries. Figure 5 shows that the delivery areas of some ports with high throughput extend to adjacent provinces, which are accessible via the transportation network. For example, as indicated by the distribution of pink dots in Fig. 5, which represents the density of cargo delivered from the Dalian port, the hinterland of the Dalian port, a major port of northeastern China, covers nearly all of northeastern China. The distribution of green dots indicates that the Qingdao port hinterland is primarily contained within its province, spreading to nearby provinces in a fan-like shape similar to the hinterlands of the Tangshan and Rizhao

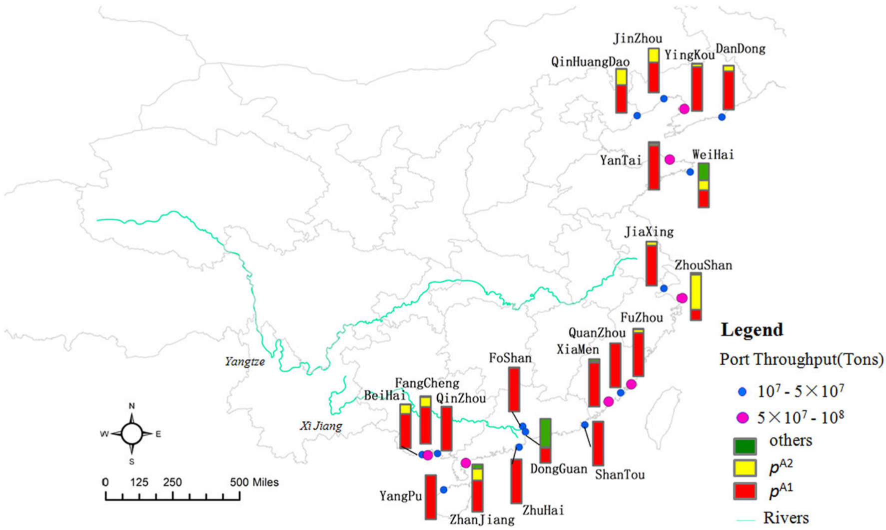


Fig. 4 Cargo flows from ports to destinations in China characterized by spatial centralization

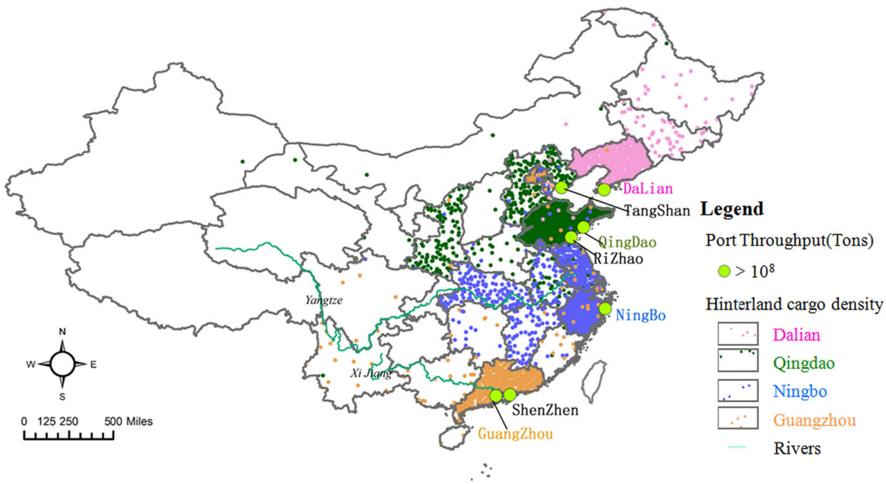


Fig. 5 Cargo flows from ports to destinations in China characterized by spatial decentralization

ports. Import cargo from the Ningbo port is primarily sent to Zhejiang Province and Jiangsu Province and partly to provinces along the Yangtze River, as is shown by the distribution of blue dots. The Guangzhou port hinterland is primarily contained within the local province, but it does spread to nearby provinces through transport networks, as shown by the distribution of orange dots. This is also true of other ports in southern China, as shown in Fig. 5.

Typically, the hinterlands of extremely large ports extend significantly inland. The two ports with the highest total import cargo value in 2012, the Shanghai and

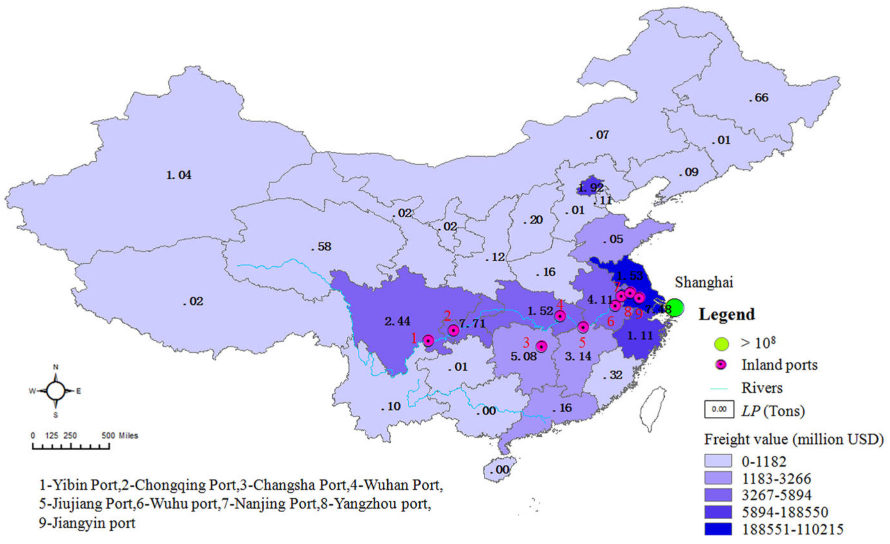


Fig. 6 Cargo flows of the Shanghai port

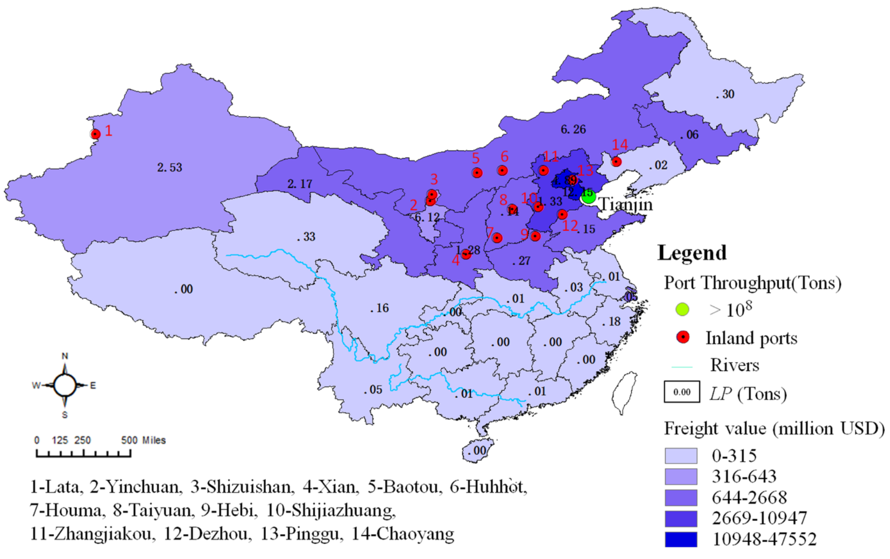


Fig. 7 Cargo flows of the Tianjin port

Tianjin ports, have regional-level port systems. As was stated by Rodrigue and Notteboom (2010), ports that focus on container transportation tend to facilitate the development of inland hubs to more competitively attract cargo. Such ports in China typically have a small HP_i but a relatively high r_i. For example, the HP_i and r_i of the Shanghai port are 0.29 and 0.81, respectively, and the HP_i and r_i of the Tianjin port are 0.29 and 0.92, respectively. Figures 6 and 7 show that the hinterlands of the

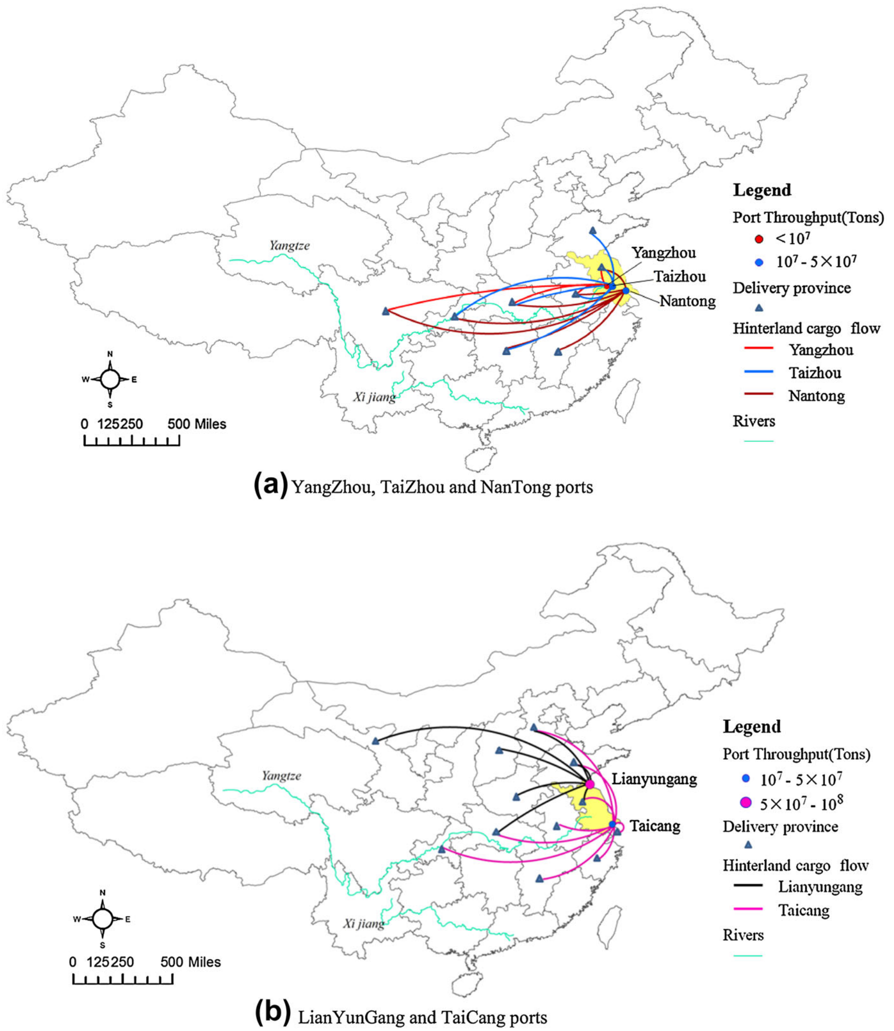
Shanghai and Tianjin ports are primarily local areas, while cargo is also widely distributed to many distant provinces. The above hinterland distributions correspond to the Yangtze River and inland port strategies adopted by the Shanghai and Tianjin ports, respectively. For example, the Shanghai port started to purchase some of the largest ports along the Yangtze River in 2003, as denoted by the pink circles in Fig. 6. The Yangtze River strategy has helped the Shanghai port attract cargo from distant cities along the Yangtze River Basin. The Yangtze River strategy has achieved some of its objectives. The Shanghai port has successfully incorporated provinces along the Yangtze River into its hinterland, which is the optimized scenario computed through the LP_{ik} index. The Tianjin port was the first port in China to operate a container-dedicated freight train in 1995 by establishing inland ports. It currently operates 14 freight rail lines connecting the Tianjin port with inland ports, as shown by the red circles in Fig. 7, serving as part of the Euro-Asia Land Bridge; all of these lines have dedicated freight trains. According to the LP_{ik} index, it can be concluded that the geographical distribution of the Tianjin port's hinterland is closely correlated with its inland port setup.

Large ports with decentralized hinterlands can be described as follows. First, as the scale of a port increases, it is able to serve more shipping lines, to improve its services and to reduce fixed costs per shipped unit concurrently. These factors enable the port to invest more in accessing distant cargo. Second, the locations and connections to hinterlands of large ports can also be important. The Shanghai port capitalizes on its ease of access to river ports to overcome the inconveniences of long-distance road transportation; the Tianjin port uses rail transportation and a quick customs entry process to ensure a similar effect. Cidell (2010) explained that there has been a change in the spatial organization of the freight distribution sector from the concentration of maritime traffic to fewer but larger ports toward the use of inland "ports" as sites of growth to alleviate congestion at terminals in the USA.

Ports in Jiangsu Province

Notably, the hinterlands of ports in Jiangsu Province are decentralized. Most of these ports are located along the lower Yangtze River and do not have high-concentration hinterlands but do have hinterlands primarily along the Yangtze River and in several other locations. For example, cargo from the Nantong port is distributed primarily to cities positioned along the Yangtze River (Fig. 8a); cargo from the Lianyungang port is distributed to northern China; cargo from the Taicang port is distributed to provinces along the Yangtze River and to the northern coastline (Fig. 8b); cargo from the Nanjing port is distributed to southern China (Fig. 8c); and cargo from the Zhenjiang port is primarily distributed to local and adjacent provinces (Fig. 8d).

The cargo distribution of ports downstream from the Yangtze River is more decentralized than that along the Xijiang River and the upper Yangtze River, where cargo distribution hinterlands are relatively concentrated. This may be due to the fact that ports along the Xijiang River have joined an organization called the "South China Common Feeder Alliance," which has made ports in this region better organized. Through the alliance, the Guangzhou and Shenzhen ports act as regional



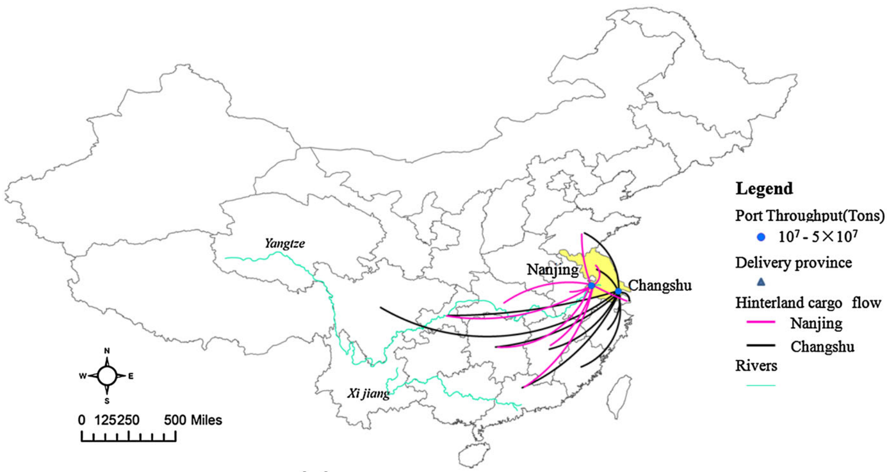
(a) YangZhou, TaiZhou and NanTong ports

(b) LianYunGang and TaiCang ports

Fig. 8 Jiangsu port cargo flows in China

hub ports that facilitate international trade, while other regional ports act as branches that facilitate local trade and that support hub ports. While the ports of Jiangsu Province are less organized, to make full use of their capacities, they likely seek out cargo sources from other provinces.

The above analysis shows that when ports are characterized by hinterland spatial concentration, cargo is delivered to local or adjacent provinces, which complies with the distance–decay principle; when ports are characterized by hinterland spatial decentralization, a small proportion of cargo is delivered to nearby areas and a larger proportion is delivered to local areas. Cargo flows still tend to decrease with



(c) Nanjing and Changshu ports

(d) Zhenjiang, Jiangyin and Zhangjiagang ports

Fig. 8 continued

distance. The mechanisms of distance–decay phenomena will be analyzed in the following sections.

Distance–decay analysis results

Distance and cargo flow results

For the ports with throughput levels of more than 100 million tons, using the Gravity model, we calculated distance–decay parameters for major ports in China, which range from −1.847 to −0.143 with an average of −1.28. The R^2 values of the models range from 0.06 to 0.528 with an average of 0.316. However, R^2 is not

Table 4 Summary of R-square results for the functions (USD)

	Gompertz	Logistic	S	Tanner	Logarithmic	Power	Exponential
Dalian	0.932[a]	0.920[a]	0.648	0.881[a]	0.849	0.689	0.130
Qingdao	0.978[a]	0.979[a]	0.861[a]	0.533	0.830	0.786	0.392
Ningbo	0.972[a]	0.969[a]	0.934[a]	0.809	0.793	0.726	0.374
Guangzhou	0.840[a]	0.835	0.949[a]	0.548	0.837[a]	0.437	0.131
Shanghai	0.898[a]	0.887	0.960[a]	0.862	0.948[a]	0.775	0.334
Tianjin	0.932[a]	0.920[a]	0.819	0.878	0.900[a]	0.721	0.237
Lianyungang	0.970[a]	0.968[a]	0.762	0.879[a]	0.293	0.718	0.293

[a] Top 3 R-squared values

Table 5 Estimated parameters of the Gompertz functions

Port	Function
Shanghai	$y = 225.517 \times 10^9 \times \exp(-1.337 \times \exp(-0.0051 \times x/10^3))$
Tianjin	$y = 105.525 \times 10^9 \times \exp(-1.886 \times \exp(-0.0073 \times x/10^3))$
Qingdao	$y = 100.639 \times 10^9 \times \exp(-1.177 \times \exp(-0.034 \times x/10^3))$
Ningbo	$y = 78.897 \times 10^9 \times \exp(-1.277 \times \exp(-0.0665 \times x/10^3))$
Dalian	$y = 57.179 \times 10^9 \times \exp(-1.461 \times \exp(-0.0035 \times x/10^3))$
Guangzhou	$y = 49.009 \times 10^9 \times \exp(-3.466 \times \exp(-0.0316 \times x/10^3))$
Lianyungang	$y = 22.428 \times 10^9 \times \exp(-1.991 \times \exp(-0.0035 \times x/10^3))$

x is the distance in meters, and y is the cumulative cargo flow in USD

significant, indicating that other factors affect cargo volumes (see also Ferrari et al. 2011). When data with poor fit are disregarded, the distance parameters are still negative, confirming that distance decay occurs in cargo flows from ports to hinterlands. The distance–decay parameters of cargo flows between ports and hinterlands are also shown to be negative in other studies: that for French ports is −2.7 (Guerrero 2014) and that for Liguria is −1.380 (Ferrari et al. 2011).

Distance and cumulative cargo flow results

Using the Gompertz function and after applying several other methods, we obtain the R-square results shown in Table 4.

From the above results, it can be concluded that hinterland cargo volumes of Chinese ports based on distance are structured in accordance with the Gompertz growth curve. With distance, the corresponding cumulative hinterland cargo volume of a port initially experiences an accelerated growth phase, reaches an inflection point at a certain distance, enters a decelerated growth phase, and finally reaches saturation.

The results of the Gompertz equation regression analysis are shown in Table 5. The raw data and forecasting curves are shown in Fig. 9.

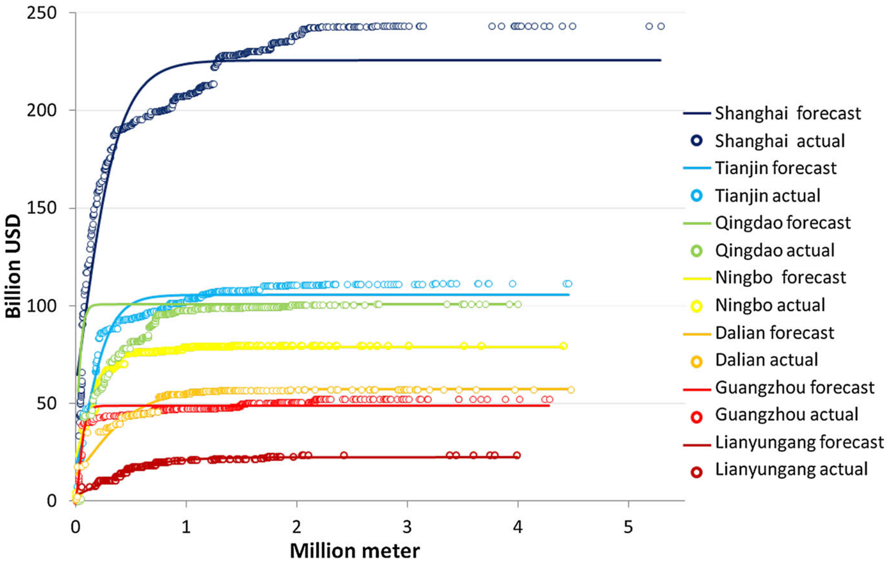


Fig. 9 Cargo flow forecast and actual curve

From our regression analysis, we find that even for ports with decentralized hinterlands, distance still significantly affects cargo flows: it seems to be easier to attract cargo over a shorter distance and more difficult to attract cargo over a longer distance. According to Fig. 9, even for very large ports, such as the Shanghai and Tianjin ports, the cargo volume increases significantly with distance when the distance is short; when the distance is larger than 500 km, the increase in cargo volume declines with distance, and the cargo volume tends to stabilize beyond a certain distance threshold.

Conclusions

This paper analyzed the relationship between cargo flows and distances for 63 Chinese ports and their hinterlands. The results show that this relationship generally follows the principle of distance decay.

The paper uses the spatial concentration indices $p_i^{A_u}$, HP_i, LP_{ik}, and r_i to categorize the import cargo hinterlands of ports as either concentrated or decentralized. Concentration indicates that discharged cargo is sent to local provinces within short distances; this typically occurs when the cargo throughput of a port is relatively low. Large ports are characterized by decentralization: when the throughput of a port increases, cargo tends to be distributed across larger distances while still remaining significantly concentrated within local or adjacent provinces; very large ports like the Shanghai and Tianjin ports have strengthened their connections to distant hinterlands by establishing inland ports, allowing them to overcome the limitations of long distances and to extend their hinterlands.

Ports with concentrated hinterlands clearly exhibit distance decay; for ports with decentralized hinterlands, the relationship between cargo volume and distance still shows signs of distance decay, but this trend is less prominent. Using the Gravity model, this paper shows that cargo volumes between ports and their hinterlands decrease as distances increase. Furthermore, the Gompertz equation and several other methods were used to analyze the relationship between distance and cumulative cargo flows for large ports. The corresponding results are satisfactory, showing that cargo flows increase rapidly with distance when the distance falls below a certain threshold, while the effect of distance on cargo flows is limited above this threshold. These results show that the hinterlands of large ports remain in local or nearby areas, and this also conforms to the principles of distance decay. This may occur because costs and benefits are balanced when consignees consider port choices. On the other hand, this suggests that the effects of investments or policies designed to attract distant inland cargo should be considered by port managers and policy makers.

The paper provides a new geographic perspective for understanding the distribution of port cargo across hinterlands. We have developed an approach and a platform for analyzing such forms of distribution that can facilitate similar research in both academia and industry.

Finally, this paper is limited in that it assumes that all cargo is transported by road, while road transport is in fact an inefficient form of long-distance cargo transport. In addition, rail and waterborne transportation can be used to reduce carbon emissions; carbon emission mitigation through a combination of modes is an interesting topic that must be discussed in the future. More emphasis should also be placed on the cost-effect ratio when considering attracting distant cargo, as potential increases in cargo volume are limited as distances increase. Many other factors affect the ways in which ports attract cargo from hinterlands, including shipping route distribution, port efficiency levels, and port usage costs. These factors will be discussed in future studies.

Acknowledgements The authors wish thank the editor and anonymous referees for their valuable suggestions, which have helped improve this paper considerably. This study was sponsored by the Social Science Foundation, by the Ministry of Education of China (Grant No. 12YJC630205), through the Shanghai Pujiang Program (Grant No. 15PJC060), and by the Shanghai Maritime University Foundation (Grant No. 20120079).

References

Blonigen, B.A., and W.W. Wilson. 2006. International trade, transportation networks and port choice. *Transportation Journal* 34: 32–47.

Chang, Y.-T., S.-Y. Lee, and J.L. Tongzon. 2008. Port selection factors by shipping lines: Different perspectives between trunk liners and feeder service providers. *Marine Policy* 32 (6): 877–885.

Cidell, J. 2010. Concentration and decentralization: The new geography of freight distribution in US metropolitan areas. *Journal of Transport Geography* 18 (3): 363–371.

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

Fan, L., W.W. Wilson, and D. Tolliver. 2010. Optimal network flows for containerized imports to the United States. *Transportation Research Part E: Logistics and Transportation Review* 46 (5): 735–749.

Ferrari, C., F. Parola, and E. Gattorna. 2011. Measuring the quality of port hinterland accessibility: The Ligurian case. *Transport Policy* 18 (2): 382–391.

Fotheringham, A.S. 1981. Spatial structure and distance–decay parameters. *Annals of the Association of American Geographers* 71 (3): 425–436.

Guerrero, D. 2014. Deep-sea hinterlands: Some empirical evidence of the spatial impact of containerization. *Journal of Transport Geography* 35: 84–94.

Herfindahl, O. C. (1950) Concentration in the steel industry. Ph.D. thesis, Columbia University, NY.

Hoare, A.G. 1986. British ports and their export hinterlands: A rapidly changing geography. *Geografiska Annaler. Series B. Human Geography* 68 (1): 29–40.

Jones, D.A., J.L. Farkas, O. Bernstein, C.E. Davis, A. Turk, M.A. Turnquist, L.K. Nozick, B. Levine, C.G. Rawls, S.D. Ostrowski, and W. Sawaya. 2011. U.S. import/export container flow modeling and disruption analysis. *Research in Transportation Economics* 32 (1): 3–14.

Leachman, R.C. 2008. Port and modal allocation of waterborne containerized imports from Asia to the United States. *Transportation Research Part E: Logistics and Transportation Review* 44 (2): 313–331.

Lee, T., G.T. Yeo, and V.V. Thai. 2014. Changing concentration Ratios and geographical patterns of Bulk Ports: The case of the Korean West Coast. *The Asian Journal of Shipping and Logistics* 30 (2): 155–173.

Levine, B., L. Nozick, and D. Jones. 2009. Estimating an origin–destination table for US imports of waterborne containerized freight. *Transportation Research Part E: Logistics and Transportation Review* 45 (4): 611–626.

Luoma, M., K. Mikkonen, and M. Palomäki. 1993. The threshold gravity model and transport geography: how transport development influences the distance–decay parameter of the gravity model. *Journal of Transport Geography* 1 (4): 240–247.

Luo, M., and T.A. Grigalunas. 2003. A spatial-economic multimodal transportation simulation model for US coastal container ports. *Maritime Economics & Logistics* 5 (2): 158–178.

Malchow, M.B., and A. Kanafani. 2004. A disaggregate analysis of port selection. *Transportation Research Part E: Logistics and Transportation Review* 40 (4): 317–337.

Martínez, L.M., and J.M. Viegas. 2013. A new approach to modelling distance–decay functions for accessibility assessment in transport studies. *Journal of Transport Geography* 26: 87–96.

Monios, J., and Y. Wang. 2013. Spatial and institutional characteristics of inland port development in China. *GeoJournal* 78 (5): 897–913.

Notteboom, T.E. 1997. Concentration and load centre development in the European container port system. *Journal of Transport Geography* 5 (2): 99–115.

Notteboom, T.E. 2006. Traffic inequality in seaport systems revisited. *Journal of Transport Geography* 14 (2): 95–108.

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

Reynolds-Feighan, A.J. 1998. The impact of US airline deregulation on airport traffic patterns. *Geographical Analysis* 30: 234–253.

Rodrigue, J.P., and T. Notteboom. 2010. Comparative North American and European gateway logistics: The regionalism of freight distribution. *Journal of Transport Geography* 18 (4): 497–507.

Steven, A.B., and T.M. Corsi. 2012. Choosing a port: An analysis of containerized imports into the US. *Transportation Research Part E: Logistics and Transportation Review* 48 (4): 881–895.

Tiwari, P., H. Itoh, and M. Doi. 2003. Shippers' port and carrier selection behavior in China: a discrete choice analysis. *Maritime Economics & Logistics* 5 (1): 23–39.

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

Wilson, A.G. 1967. A statistical theory of spatial distribution models. *Transportation Research* 1 (3): 253–269.

Yuen, C.A., A. Zhang, and W. Cheung. 2012. Port competitiveness from the users' perspective: An analysis of major container ports in China and its neighboring countries. *Research in Transportation Economics* 35 (1): 34–40.