# Path to a multilayered transshipment port system: How the Yangtze River bulk port system has evolved

**Abstract:** China's steel output has maintained rapid growth over the past twenty years. Due to this, a large number of iron ore ports/terminals have been built along the Yangtze River, and the Yangtze River bulk port system has experienced a unique development in its structure. This paper aims to understand the evolution of this bulk port system[1] along the Yangtze River. To achieve this objective, first the development phases of the Yangtze River bulk port system are reviewed, taking the theoretical (container) port evolution model as a benchmark. Then several hypotheses addressing certain features of bulk port system development are proposed, followed by using panel data analysis to test these hypotheses. Based on this discussion and analysis, the major driving forces that are reshaping bulk port development along the Yangtze River are then summarized. It is found that evolution of the Yangtze River bulk port system in general follows the port development models in previous literature. However, the trend towards regionalization and an offshore hub have not appeared. Besides this, iron ore transshipment is moving outward both for sea ports and river ports, and few iron ore transshipment gateway hubs are occurring. Furthermore, the transshipment function of a bulk port plays a significant role in port traffic changes, but this role is affecting sea ports differently to river ports. The container throughput of transshipment sea ports has a significant negative effect on bulk traffic, whereas that of transshipment river ports has a positive effect. Geographical conditions, institutional factors and national policy, industry agglomeration, changes in market supply and demand, and technology updates are major factors driving changes to the port system structure. These factors are observed to function either individually or collectively at different development stages.

**Keywords:** Inland river shipping, Bulk port system evolution, Port development model, Panel data analysis

[1] In this paper, bulk cargo mainly refers to iron ore bulk cargo.

## 1 Introduction

China has been the world's leading producer of steel since 1996, and in 2014 its steel production reached 822.7 million tons. This ranked No. 1 in the world, and was almost 8 times that of Japan's production (110.7 million tons), which ranked No. 2 (World Steel Association).

Iron ore is the main raw material needed for steel production, yet China's domestic supply of iron ore is far from meeting the demand for its steel production. Thus, every year China imports massive amounts of iron ore from other countries. For example, 933 million tons were imported in 2014, which accounted for 80.1% of the total demand in China. Since the 1950s, many steel manufacturers have been founded alongside the Yangtze River, and Table 1 lists each major steel manufacturer, together with its year of founding and paired port.

Table 1. Major steel manufacturers and year of founding

| Port | Steel Plants | Year | Port | Steel Plants | Year |
|---|---|---|---|---|---|
| Shanghai | Baosteel | 1985 | Suzhou | Sha Steel | 1992 |
| Nanjing | Nanjing Steel | 1959 | Suzhou | Yonggang Steel | 1984 |
| Jiangyin | Xingcheng Steel | 1993 | Ma'anshan | Ma Steel | 1993 |
| Jiujiang | Nanchang Steel | 2001 | Wuhan | Wuhan Steel | 1958 |
| Chenglingji | Valin Steel | 1997 | Chongqing | Chongqing Steel | 1997 |

Sources: Steel manufacturers' web sites.

Iron ore is the most important bulk cargo shipped along the Yangtze River. To support such fast growth in imported iron ore along the Yangtze River, over recent decades many bulk ports or terminals have been constructed in this region. Shanghai, Ningbo, Zhoushan and Lianyungang are four sea ports close to the Yangtze River that act as transshipment gateway ports between ocean transportation and river transportation. Due to its unique geographical features, the Yangtze River can be divided into three segments, namely, the mouth of the Yangtze River, the low Yangtze River and the middle and upper Yangtze River, as Figure 1 shows. Ports at the mouth of the Yangtze River have good water depth, and can accommodate ships of up to 200,000 dwt (Dead Weight Ton). The water depths of ports along the lower Yangtze River vary though; for instance, Suzhou and Nantong, which are located at the mouth of the Yangtze River, have a 12.5-meter water depth, and can handle ships of 150,000 dwt. The water depths at Jiangyin and Nanjing are approximately 7 to10 meters, and can therefore only accommodate ships of 50,000 to 100,000 dwt, depending on the tide. Ports upstream of Nanjing, such as Ma'anshan, Wuhan and Chongqing, can only be accessed by smaller ships of maximum 10,000 dwt, due to the low height permitted by the Nanjing Yangtze River Bridge. Figure 1 shows a map of ports along the Yangtze River.

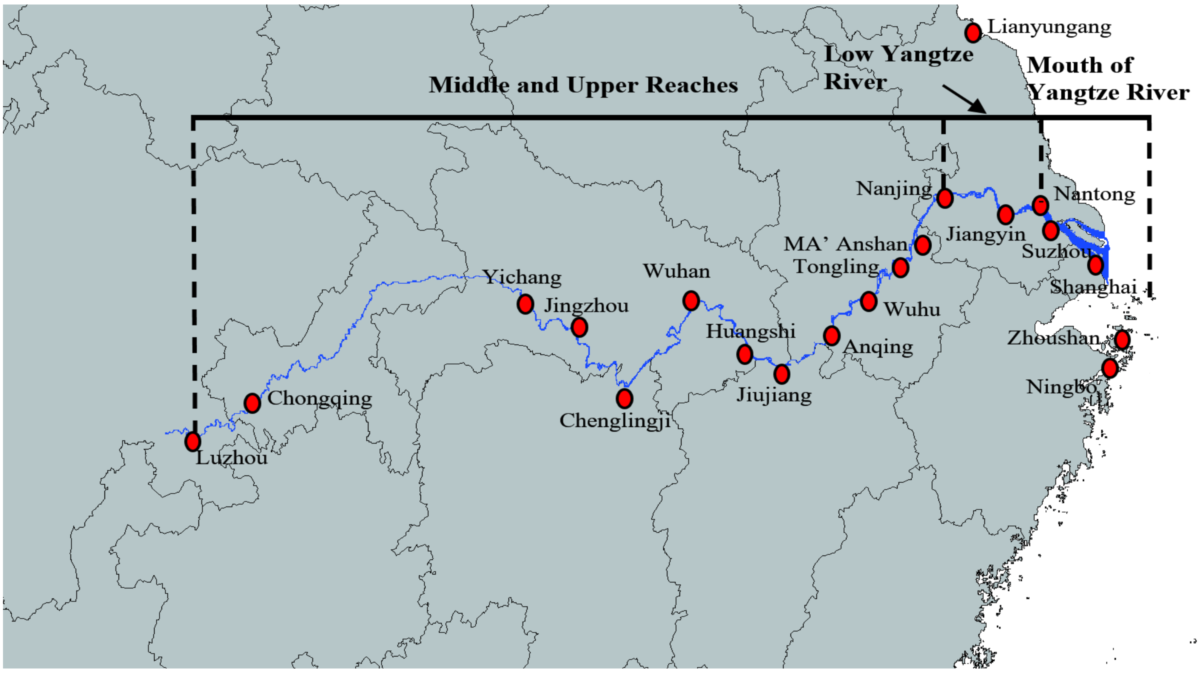


Figure 1. Main ports and their corresponding steel manufacturers along the Yangtze River

Since 1960, the evolution of port networks has attracted a lot of attention, and in recent years, some researchers have also extended their studies to river port system evolution, such as the Pearl River Delta port system (Wang, 1998; Wang and Slack, 2000; Liu et al., 2013) and the Yangtze River port system (Veenstra and Notteboom, 2011; Wang and Ducruet, 2012; Zheng and Yang, 2016). However, it is noted that all these studies focus only on container ports. Over the past 30 years, though, the bulk port system along the Yangtze River has developed very quickly and experienced dramatic changes. It is therefore of great benefit to investigate the evolution of this bulk port network along the Yangtze River by answering the following questions: What has been the development path of the bulk port system along the Yangtze River? What are the differences between the development path of a container port system and a bulk port system? What are the driving forces that shape the structure of a bulk port system? This paper aims to address these questions by first reviewing the development phases of the bulk port system along the Yangtze River, and then conducting an empirical analysis.

This paper attempts to augment the existing literature on port systems by adapting port development models to river ports, and by adding the development pattern of a bulk port system. In addition, this paper will employ panel data analysis, using a significant amount of data to empirically test several hypotheses that are inspired by the proposed questions. It is believed that this paper will substantially increase the understanding of a theoretical port development model, as well as provide clues that will assist the future development of bulk port systems on inland rivers.

The paper is organized into five sections. Section 2 reviews and summarizes existing literature on port system evolution. Section 3 analyzes the development phases of the Yangtze River bulk port system whilst constantly referring to the theoretical port development model. Section 4 empirically tests several hypotheses regarding certain features of bulk port system development. Based on this analysis, Section 5 summarizes the major driving forces involved, and Section 6 highlights the conclusions that can be drawn.

# 2 Literature review

Taaffe et al. (1963) initially studied the development of a port transport network in Ghana and Nigeria. Hayuth (1981) put forward the concept of containerization and load centers, and divided the port evolution process into five phases: Conventional ports, container ports, port concentration and inland penetration, load centers, and port decentralization. Notteboom (1997) introduced Hayuth's model when analyzing the port system in Europe, and compared the differences between European and US port systems. He pointed out that the concentration of European ports was a result of container traffic shifting to medium-sized ports, rather than just the challenges from peripheral ports. Later, Notteboom and Rodrigue (2005) added the port regionalization phase to the port development path, which links gateway sea ports to the inland transport network. Rodrigue and Notteboom (2010) extended this conceptual structure by introducing foreland regionalization, which refers to the capture of maritime hinterland by intermediate offshore hubs, and the integration of transshipment hubs into regional shipping networks.

Hayuth and Notteboom’s classic port development conceptual models were widely applied in studying regional port systems all over the world, and were adjusted for geographical scale. Notteboom (2006) described port regionalization in the port of Antwerp, which started to develop the hinterland network, including inland terminals and logistic poles. Wilmsmeier and Monios (2013) identified a potential deconcentration of container traffic within the UK port system, with a shift from gateway ports to transshipment hubs. Wilmsmeier et al. (2014) examined the container movements of Latin America and the Caribbean between 1997 and 2012. They performed a detailed analysis of the evolution from mature hub-and-spoke networks and port devolution to the undermining of the hubs and the rise of new secondary hub-and-spoke networks.

The container port system in the Pearl River Delta (PRD) in China has also attracted a lot of attention. Wang (1998) divided the evolution of the PRD port system from the 1970s to 1995 into three stages, during which Hong Kong Port changed from initially being a container port to becoming a sole container hub, with Hong Kong's terminal operators penetrating into other mainland ports during the final stage. Wang and Slack (2000) further investigated the changing roles of Hong Kong Port and other ports in the PRD. They concluded that a regional system of multiple ports was taking shape, and that Shenzhen was developing into a deep-sea direct service port. The driving forces can be classified into marketing factors such as cost-based competition and multi-modal accessibility, technological factors such as container standardization, and institutional factors such as the "one country, two systems" policy. Rodrigue and Notteboom (2010) listed the Shenzhen–Hong Kong port cluster as an example of hinterland-dominated regionalization. Liu et al. (2013) commented that the PRD port system had developed from a one gateway port (Hong Kong) to two (Hong Kong and Shenzhen), and that they were now undergoing regionalization, with a specialized direction. International shipping liner services and market access were identified as two major forces reshaping port development in the PRD. Recently this research has been extended to inland rivers. Veenstra and Notteboom (2011) investigated the structure and development of the Yangtze River port system, and found that, unlike the standard container port development model (Veenstra and Notteboom, 2005), deconcentration took place in the very early stage of port development, and the Yangtze River container port is now going through a regionalization phase, with the process now moving from the lower Yangtze River to further upstream. They also found that the geography of the river itself is one of the determinants in the development of the river port system. Wang and Ducruet (2012) analyzed the emergence of Yangshan as sole transshipment hub in the Yangtze River Delta, and confirmed the offshore hub development and port regionalization process, which is occurring earlier than in normal cases. They identified that political and institutional factors are the major reasons for such deviation from the classic model. Zheng and Yang (2016) proposed a mixed-integer linear programming model, factoring in ship operation and container handling costs for

Yangtze River container shipping. Their findings support the trend toward cargo concentration and port regionalization along the Yangtze River.

Table 2 summarizes the literature on theoretical port development models and their applications. Most of the previous works center on the development stages of a container port system. Although the port systems in different regions have gone through distinct stages and various moves in diverse directions, many researchers deliberated over the rise of secondary ports during the port evolution process. The common driving factors are found to be land constraints along with high cost and congestion in the original hub port. Although much research has gone into studying port systems in different regions, comparatively little research has focused on bulk ports. Our paper is therefore unique in investigating the evolution of the bulk port system along the Yangtze River. The similarities and differences between the evolution of a bulk port and a container port system will be addressed, and the driving factors behind the differences will be summarized.

Table 2. Literature about theoretical port development models and their applications

| Author(s) | Research objective(s) | Findings | Driving factors |
|---|---|---|---|
| Taaffe et al. (1963) | Ghana and Nigeria port system | Six phases: (1) Scattered ports; (2) penetration and port concentration; (3) development of feeders; (4) interconnection; (5) complete interconnection; (6) emergence of high-priority main corridors. | (1) Distribution of resources; (2) road and rail infrastructure; (3) population pattern. |
| Hayuth (1981) | U.S. port system | Five phases: (1) Conventional port; (2) container port; (3) port concentration and inland penetration; (4) load center; (5) port decentralization. | (1) Containerization; (2) economies of scale in carrier and port operations. |
| Notteboom (1997) | European container port system | Concentration and load center development. | (1) Establishment of mega consortia in the shipping sector; (2) development of hinterland networks and corridors; (3) port policy issues regarding port infrastructure developments. |
| Wang (1998) | Chinese Pearl River Delta container port system | Three phases: (1) Initial container port; (2) sole container hub; (3) penetration to mainland ports. | (1) No competition in the second stage due to regulation in mainland China; (2) land limit and high cost in the third stage. |
| Wang and Slack (2000) | Chinese Yangtze River Delta port system | Hong Kong kept as hub port and Shenzhen developed into a direct ocean shipping port as well as a feeder port. | (1) Cost-based competition; (2) impact of the "one-country two-systems" policy; (3) the impact of globalization and container standardization; (4) the impact of multi-modal accessibility. |
| Loo and Hook (2002) | Hong Kong port | Shift of cargo transshipments from North and Central China to South China, and rapid container port development in the PRD. | Developments in China's national transport system and rapid export-oriented industrialization of the PRD. Market forces cannot fully explain the evolution, as political and other policy considerations are of equal importance. |
| Notteboom and Rodrigue (2005) | New York and New Jersey port inland distribution network | Concept of port regionalization. | Local constraints. Global changes in production and consumption distribution. |

| Author(s) | Research objective(s) | Findings | Driving factors |
|---|---|---|---|
| Notteboom (2006) | Antwerp port | Port regionalization towards developing hinterland network. | Hinterland overlaps and port rivalry in the region. |
| Notteboom (2010) | European container port system | Container ports go through deconcentration processes whilst far more concentrated than other cargo handling ports. | Port rivalry in gateway regions for contestable hinterlands, as well as institutional factors. |
| Rodrigue and Notteboom (2010) | Baltic port system and Pacific Asia gateway ports | Foreland-based regionalization. | Vulnerability of intermediate hubs and intention of consolidating positions in liner service networks. |
| Veenstra and Notteboom (2011) | China's Yangtze River Delta container port system | (1) Concentration patterns at the side of the seaport system; (2) regionalization phase of Shanghai port and moving upstream. | Large ocean cargo volumes and inequality in operations along the river. |
| Wang and Ducruet (2012) | Shanghai–Yangshan multilayered gateway port | (1) Container flows concentrated on Shanghai in the early phase; (2) offshore hub development and regionalization process, occurring earlier than usual. | (1) Administrative choice in transition from command to market economy; (2) national policies and government support. |
| Liu et al. (2013) | China's Pearl River Delta container port system | One gateway port (Hong Kong) becomes two (Hong Kong and Shenzhen) and undergoes regionalization with specialization. | International shipping liner services and market access. |
| Wilmsmeier and Monios (2013) | UK container port system | Deconcentration process, with a shift from gateway ports to transshipment hubs. | Container technology revolution and increasing vessel size. |
| Wilmsmeier et al. (2014) | Latin America and the Caribbean port system | Port deconcentration and the emergence of secondary ports. | Significant and continued growth of container traffic; manufacturing locations; shipping line strategies; contingency of both private investment and public planning approval. |
| Zheng and Yang (2016) | Yangtze River container port system | Cargo concentration and port regionalization along the Yangtze River. | Profitability maximizing and operational optimization. |

## 3 General model of bulk port system development along the Yangtze River

The big difference between inland shipping and ocean shipping is that, due to draft limitation, transshipments occur much more often, and this has led to the appearance of multilayered iron ore gateway hubs in inland rivers. Notteboom and Rodrigue (2007) first presented the multilayer port development model. They defined that the transport layer involves the operation of transport services on links and corridors between the port and other nodes and the transshipment operations in the nodes of the system. Wang and Cheng (2010) further explained that ports and airports form multilayer hubs for their regions to link up with the rest of the world. Wang and Ducruet (2012) argued that the container port system on the Yangtze River has evolved into a polycentric, yet more compact, multifunctional and multilayered gateway centered upon Shanghai. The imported iron ore is also subject to multilayered transshipment among the aforementioned segments in the Yangtze River. Since there is no iron ore mine in the Yangtze River Delta and the fact that iron ore is rarely transported by rail and truck from other regions to lower Yangtze River ports, the volume of transshipped iron ore can be considered to be the same volume of iron ore that comes through the gateways.

Figure 2 illustrates the development of iron ore throughputs and the number of major iron ore ports along the Yangtze River from 1981 to 2014. It is noted that the port throughputs and number of major ports in the three Yangtze River segments vary significantly at different time periods. Referring to previous studies and the principles used to separate the port system development stages, we can divide the development of the bulk port system along the Yangtze River into five stages, based on the changes in iron ore throughput, transshipment traffic at the port level, and the changes in number of ports.

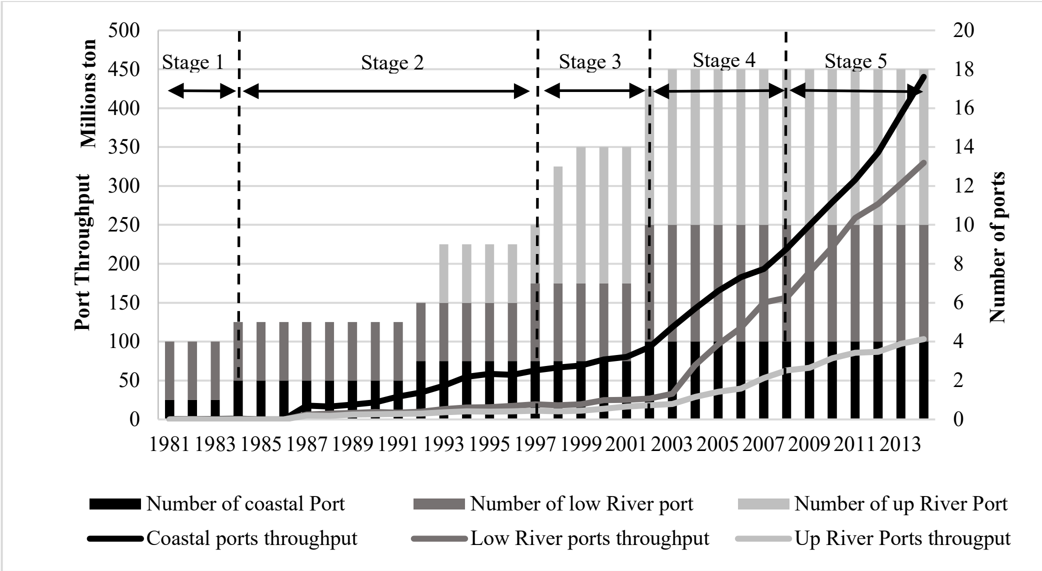


Figure 2. Development of iron ore throughputs and number of ports along the Yangtze River

### 3.1 Sole gateway sea port and scattered river ports (prior to 1984)

Prior to 1984, China was in the era of planned economy, with all ports being directly administrated by the Ministry of Transportation. Annual transport planning was carried out by the Ministry of Transportation (MOT) China and implemented by the Yangtze River Shipping Bureau. During this period, the bulk port system along the Yangtze River was in a simple form. Shanghai, due both to its advantageous location at the mouth of the Yangtze River and to its economic position, was the only port at that time handling iron ore transshipment. From 1981 to 1984, Shanghai's iron ore transshipment volumes increased from 223 thousand tons to 414 thousand tons, which accounted for about 80% of the total inflow volume of iron ore.

After the reform and opening up in 1978, congestion began to occur at Shanghai port due to its poor facilities combined with the sudden increase in import cargo. In 1981, Zhenjiang and Nanjing were selected by MOT China as two candidate ports for alleviating the congestion in Shanghai by developing the bulk transshipment business along the Yangtze River. As part of the national plan, the Dagang Port project in Zhenjiang was commenced in 1982 and completed in 1985, and the Xinshengwei Port project in Nanjing was completed in 1984. Prior to 1985, Nanjing and Nantong were the only two ports downstream in the Yangtze River that had iron ore throughput.

During this phase, steel manufacturers deep along the Yangtze River, such as at Wuhan and Chongqing, were still self-sufficient, and therefore ports in the middle and upper Yangtze

River had no iron ore throughput.

### 3.2 Formation of a dual gateway port with double transshipment (1984-1997)

In 1984, the Yangtze River Shipping Corporation was established, with a view to its implementing the shipping plan along the Yangtze River, rather than it being done by the Yangtze River Shipping Bureau. Starting in 1987, port reform was carried out in China. By 1989, 26 major ports along the Yangtze River were transferred into a semi-decentralized or dual-administration system, being jointly controlled by both the MOT and local governments (Qiu, 2008). From then on, shipping activities were no longer under a unified administration. Rather, they were decided by a mechanism of coordination among shippers, ports and carriers, which greatly liberated the shipping industry's productivity.

Into the 1990s, many new steel manufacturing plants were built along the Yangtze River, which caused the demand for iron ore along the Yangtze River to rise abruptly. Due to competitive iron ore price, massive amounts of imported iron ore began to be shipped to river ports, even reaching ports deep upstream. Due to the waterway's draft limit and the limited height allowed by the Nanjing Yangtze River Bridge, only 5,000 to 10,000 dwt ships could sail to the upper reaches of the river above Nanjing. Thus, a double transshipment system was formed: The iron ore was first transshipped via a sea port, and then further transshipped via a river port in the low Yangtze River to the upper reaches of the river.

During this phase, although Shanghai's iron ore throughput increased from 764 thousand tons in 1984 to 25 million tons in 1997, its leading position was overtaken by Ningbo, whose iron ore throughput increased from 179 thousand tons in 1984 to 36 million tons in 1997. This was because Shanghai, as the economic center of China, changed its port development strategy and, since 1990, began to focus more on building an international container hub port. As evidence of this, Shanghai's container throughput increased from 0.46 million TEU in 1990 to 2.5 million TEU in 1997. It is also worth noting that, with the founding in the 1990s of Baosteel, which is the largest steel group in China, the imported iron ore at Shanghai port was used more to satisfy local demand than for transshipment. Shanghai's iron ore transshipment rate thus declined from more than 80% in the early 1980s to only 28% in 1997. Meanwhile, Ningbo, exerting its perfect draft condition and geographic advantage, seized this opportunity to take over iron ore transshipments from Shanghai. In 1997, around 88% of iron ore loaded at Ningbo was for transshipment. So, up until the end of the 1990s, a dual transshipment sea port system had been formed.

In the lower reaches of the Yangtze River, following completion of the port projects in Zhenjiang and Nanjing, these two ports achieved a rapid growth in iron ore throughput. Their total throughputs reached 6.17 million and 6.42 million tons, respectively, in 1997. Nantong is located on the opposite bank to Shanghai, and in 1991, as part of the national "Seventh Five Year Development Plan", 25 million RMB was invested in building three 10,000 tonnage bulk berths and six 20,000 tonnage bulk berths. The project was completed in 1993 and Nantong enjoyed 5.6 million tons throughput of iron ore in 1997. It should be noted that Nantong and Zhenjiang are purely transshipment ports, with a 100% transshipment rate. Due to expansion of the Nanjing Steel Corp, most of the imported iron ore loaded at Nanjing was for Nanjing Steel, with only 37% being transshipped in 1997 to the middle and upper river areas.

During this phase, the throughput of iron ore in ports deep along the Yangtze River also increased quickly. For example, the throughput of iron ore at Wuhan increased from 3.7 million tons in 1987 to 6.28 million tons in 1997, and that of Chongqing increased similarly from 25 thousand tons to 1.1 million tons. All these throughputs were accounted for by iron ore imports.

### 3.3 The peak of port concentration (1998-2002)

To satisfy the requirements of China's fast economic growth, a port system deregulation reform was undertaken from the late 1990s up to March 2002 so as to improve the efficiency of the port industry. The period from the late 1990s to March 2002 can be regarded as an important turning point in the Yangtze River bulk port system. This reform allowed the management of national ports to be transferred to local governments, which liberated port productivity and allowed the iron ore port cluster to develop in the downstream reaches of the Yangtze River. Following a decree issued by the State Council of the People's Republic of China, the management of 37 ports was transferred to local governments (Qiu, 2008). Port corporations, operating as commercial organizations, were successively established. This reform first took place in the major ports, and then spread to the newly emerging ports. During this period, a pure market mechanism was gradually created for the Chinese port industry.

The Herfindahl–Hirschman Index (HHI) is an indicator widely applied to measure the degree of concentration among firms in the industry. A high HHI indicator denotes a high level of concentration. The formulation of HHI can be shown as (Rhoades, 1993):

$$HHI = \sum_{i=1}^{i=n} \left(\frac{T_i}{\sum T_i}\right)^2,$$

where $T_i$ is the market size of the $i^{th}$ firm, whereas in this case it is the port throughput. In order to make a comparison, we calculate the HHI index by dividing the ports into sea ports and lower Yangtze River ports. The results are shown in Figures 3 and 4.

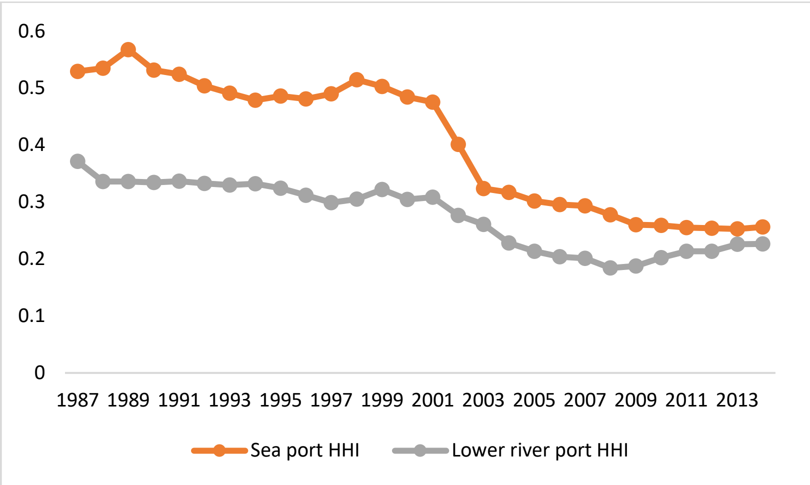


Figure 3. HHI of YRD iron ore port throughput

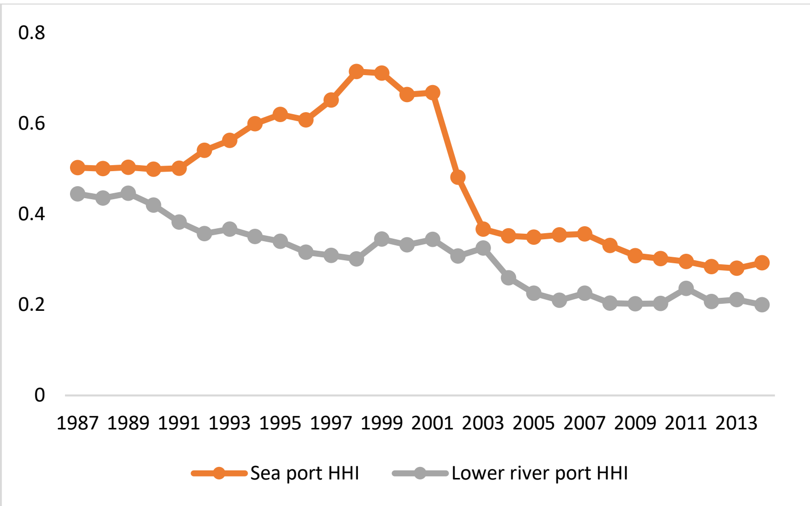


Figure 4. HHI of YRD iron ore port transshipment throughput

It can be seen that the HHI of port throughput and port transshipment volumes, after a long term decrease, both re-grew to a peak in 1998 or 1999, and then remained stable until a sharp decline in 2002 or 2003. This is because the capacity of the major ports was filled rapidly at the start of port reforms beginning in 1998. After that, many new ports and terminals were built, and after 2002 these were quickly filled to capacity by the soaring imported volume of iron ore.

By 2002, the number of transshipment sea ports had jumped to four, Zhoushan and Lianyungang appearing alongside Shanghai and Ningbo. Zhoushan is an island city close to Ningbo, and enjoys a perfect geographic location and water draft condition. In 1997, "Zhoushan Port General Layout Plan" was issued, and Zhoushan Port Corporation was founded in 1999. Lianyungang Port Authority was established in 2002. Lianyungang has a good railway connection to its hinterland, and because of its good inland transportation system it has a low water to water transshipment rate. The transshipment volumes of Zhoushan and Ningbo were also comparatively low during this phase, with Zhoushan having 2.7 million tons and Lianyungang only 0.13 million tons in 2002.

In the downstream section of the Yangtze River, by 2002 an iron ore port cluster had formed, this including six ports, namely, Suzhou, Nantong, Jiangyin, Changzhou, Zhenjiang, and Nanjing. In 2002, the ports of Taicang, Changshu and Zhangjiagang were merged and unified as the Suzhou Port Corporation. Suzhou port is located at the mouth of the Yangtze River beside Shanghai, and has a good water depth condition. In 2002, Suzhou's iron ore throughput surpassed Zhenjiang's and ranked No. 3 in the region. Jiangyin port neighbors on Suzhou, and is the last port capable of accommodating 150,000 dwt ships, though only at high tide. Jiangyin's iron ore throughput ranked No. 5 in the region.

In the middle and upstream locations of the Yangtze River, four ports, including Ma'anshan, Wuhu, Wuhan and Chongqing, had over one million tons of total iron ore throughput in 2002. All throughputs to the upper river were transshipped via ports in the downstream section.

### 3.4 Port development and traffic decentralization (2003-2008)

After 2003, the port industry in China entered a golden period. On one hand, the overall development of bulk ports can be attributed to the fast domestic economic growth, which stimulated the demand for steel. On the other hand, China's accession to the WTO in 2001 also greatly prompted more international trade and thus further stimulated a quick growth in

Chinese ports (Yang and Chen, 2014). Many ports were built to support the increase in traffic during this stage. With the boom in ports, iron ore traffic started to decentralize once again, as evidenced by the steep decline in the HHI since 2003 for both port throughputs and port transshipment volumes, as shown in Figures 3 and 4.

On the sea side, the iron ore transshipment throughputs of Zhoushan and Ningbo have, since 2003, both exceeded Shanghai, making them the regional iron ore transshipment centers. In the lower Yangtze River, apart from Changzhou, the iron ore throughput of the other five major ports all exceeded 10 million tons. In the upper river, the throughput of all the ports exceeded 1 million tons.

During this stage, the function of ports started to be differentiated. The ports could be generally divided into transshipment ports and non-transshipment ports in terms of their transshipment rate, which is closely related to whether there are giant steel plants nearby. For example, the ports of Zhoushan, Ningbo, Nantong, and Zhenjiang have no or only small steel plants nearby, so the transshipment ranges of these ports are all over 80%. Shanghai, Suzhou, and Nanjing all have giant steel plants nearby, so they have a relatively low transshipment rate (less than 50%). For simplicity, we define a transshipment port as being a port whose transshipment rate is over 80%, and other ports as being non-transshipment ports. Table 3 summarizes the transshipment ports along the Yangtze River.

Table 3. Transshipment ports along the Yangtze River

| **Ports** | **SH** | **NB** | **ZS** | **LYG** | **SZ** | **NT** | **JY** | **CZ** | **ZJ** | **NJ** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Trans Rate** | 34% | 84% | 98% | 12% | 53% | 99% | 42% | 48% | 97% | 30% |
| **Trans Port** | | √ | √ | | | √ | | | √ | |

Source: Calculated from statistics given in the China Shipping Industry Development Report.

It is also worth noting that the giant steel plants strategically invested in terminals at the dominant transshipment ports, so as to guarantee that their demand can be transported on time. For example, Ma'jishan Terminal at Zhoushan is owned by Baosteel, and Liangtan Terminal at Zhoushan is owned by Wuhan Steel. These giant steel plants also invested in more than one transshipment port, so as to avoid the risk of being charged an exorbitant price by a sole transshipment port. This behavior also speeded up the decentralization process of iron ore ports.

### 3.5 Transportation structure transition (2009-2014)

In 2008, the global financial crisis not only hit global industry heavily, but it also hit the trade and port industries. To maintain the increase of its domestic economy, the Chinese government at the end of 2008 issued a bailout by investing 8 trillion RMB on infrastructure construction, which sustained the quick growth in steel output. This quick growth continued until 2011, when steel production capability began to exceed demand. The capacity utilization of steel production in China, which can be seen as an indicator to measure whether potential output levels are being met or used, dropped to 72% in 2012 from over 80% in 2011.[2]

By 2014, Zhoushan had already grown to be the largest iron ore gateway port. Its throughput reached 139 million tons, which was 34 million tons more than Shanghai and 32 million tons more than Ningbo. In the downstream section of the Yangtze River, Nantong and Suzhou achieved the fastest growth during this stage, their throughputs being far ahead of the other ports in this segment. In particular, the throughput of Suzhou reached 127 million tons, which was even more than Shanghai and Ningbo. Also, although Nantong had a throughput of only 61 million tons, this was purely a transshipment volume and was thus equal to the transshipment volume of Shanghai.

These facts indicate a network structure change in the bulk port system along the Yangtze River, with transshipment hubs moving outward, both for sea ports and river ports. Specifically, sea side transshipment hubs shifted from Shanghai (Waigaoqiao) to Zhoushan and Ningbo, which are about 200 kilometers away from the mouth of the Yangtze River. The river iron ore transshipment hubs moved from ports in the deep lower Yangtze River, such as Nanjing and Zhenjiang, to Nantong and Suzhou, which are located at the mouth of the Yangtze River. This transition can be attributed to steel production overcapacity, which led to a significant reduction in the profit rate of the steel plants. As Figure 5 shows, the profit rate of steel plants in China dropped to 0.04% in 2012 from over 7% in 2007.

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[2] Source: Overcapacity in iron and steel industry in China: current situation and countermeasure. 21st Century Business Herald. http://finance.ifeng.com/a/20150318/13560714_0.shtml

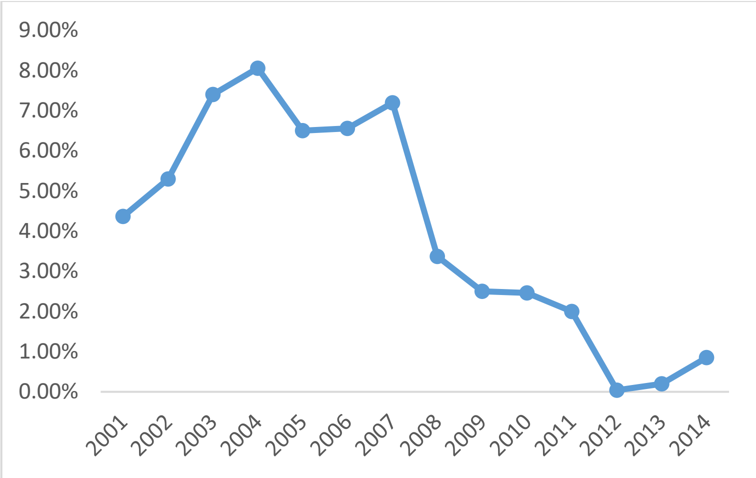



Figure 5. Operating profit of China's steel industry

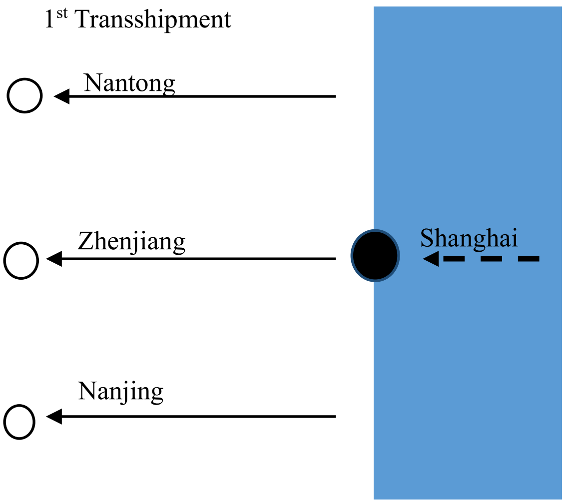
Source: MPI, TNC Steel database

In response to this decrease in profit, the pressure on shippers to reduce the freight rate became ever stronger. To compensate, they tended to employ larger ships, and to reduce the number of transshipments, since a greater number of loading and unloading operations increase the cost. Subsequently, ports located at the sea/river interface having a good water depth condition spotted a development opportunity. So, to cater for the shippers' desires, ports having a good geographic location began to invest heavily in the construction of deep-water terminals that could accommodate larger ships. Table 4 shows the large terminals built in 2013. These deep-water terminals were not only built at sea ports but also at river ports, such as Suzhou, Nantong and Jiangyin. With more and more transshipments occurring at these ports using large vessels, the traditional single transshipment mode began changing toward the multilayered transshipment mode, an indistinct trend toward hub centralization thus beginning to appear.

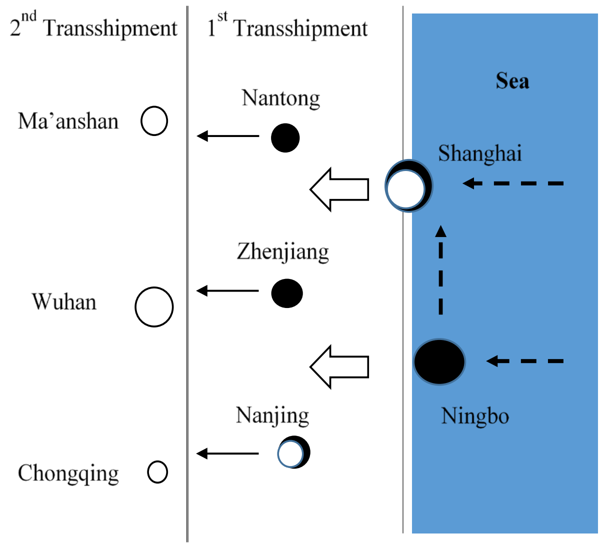
Table 4. Large bulk terminals built at Yangtze River Ports in 2013

| Port Name | No. of Terminals | Depth | Berth Capacity ('1000 tons) |
|---|---|---|---|
| Shanghai | 4 | -12.9 | 250 |
| Ningbo | 2 | -20.8 | 200 |
| Zhoushan | 2 | -24.2 | 300 |
| Lianyungang | 3 | -21 | 300 |
| Suzhou | 2 (1) | -16.5 (-12.5) | 250 (100) |
| Nantong | 2 | -16 | 150 |
| Jiangyin | 2 | -12.5 | 150 |

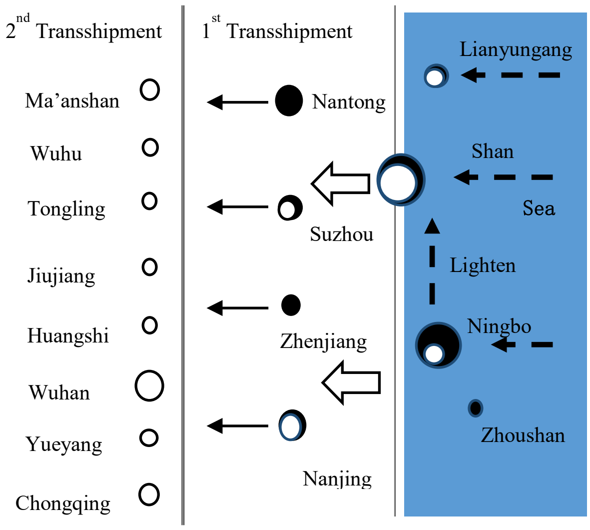
Source: Homepage of Ports and Yearbook of Chinese Ports



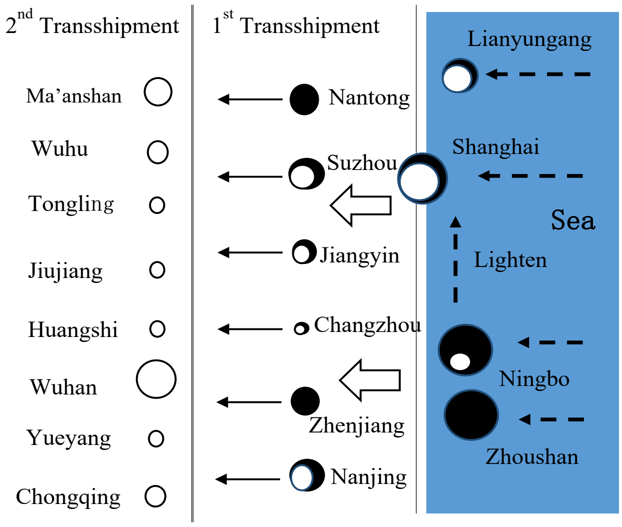

Stage One: A sole gateway sea port and scattered river ports (prior to 1984)



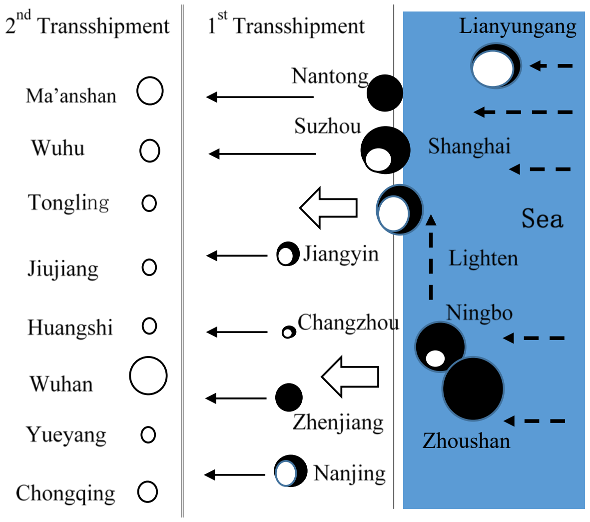

Stage Two: Formation of a dual gateway port and double port transshipment (1988-1997)




Stage Three: Peak of port concentration (1998-2002)




Stage Four: Port development and traffic decentralization (2003-2008)




Stage Five: Transshipment structure transition (2009-2014)

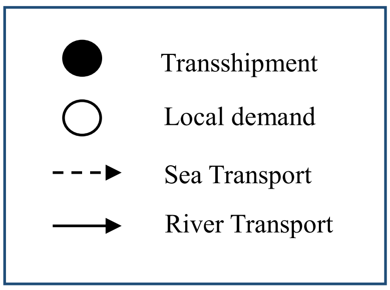


Figure 6. Yangtze River bulk port spatial development model

Source: Author's composition using data from China Ports Yearbook, China Shipping Industry Development Report (2005-2015) and China Compendium of Statistics of Industry, Transportation (1949-1999)

From the above analysis, we can conclude that the evolution of the Yangtze River bulk port system in general follows the theoretical port development model. For example, it develops from a one gateway port to a dual gateway port, from concentration to decentralization (Notteboom and Rodrigue, 2005). However, it also shows a deviation from the general model. First, the trend of the regionalization process of the Yangtze River container port system observed by Veenstra and Notteboom (2011) and the offshore hub mentioned by Wang and Ducruet (2012) have not appeared in the development of the bulk port system. The reason for the absence of this regionalization phase is that inland logistic integration is not necessary for iron ore transportation. Container cargoes are generally valuable commodities consumed by urban residents, so they need to be further transported to hinterlands after being unloaded in ports, whereas iron ore throughput is simply related to the steel industry. Although the steel industry can be regarded as the foundation of regional economic development (Krausmann et al., 2009), a steel plant is not necessarily close to a city. In fact, most steel plants are located near to the ports, both to reduce pollution in populated areas and, more importantly, to save on logistic costs. Besides, a unique double bulk port transshipment system was formed in the 1990s, triggered mainly by the geographical features of the Yangtze River. Now, with the decline in profitability of steel production, iron ore transshipment is moving outward, both for sea ports and river ports. Several iron ore gateway hubs are thus emerging, which is different to the evolution seen in container port systems.

# 4 An extended analysis of the bulk port system development

Based on the observations made in Section 3, a panel data analysis is conducted in this section in order to understand the various features of the iron ore transshipment network structure transition of the Yangtze River port system.

## 4.1 Hypotheses and model

Following on from the discussion in the previous section, certain questions arise. For example, is the development of iron ore throughput in any way related to container throughput? It is noted that Zhoushan, as the largest transshipment sea port, enjoyed an obviously faster growth of iron ore traffic compared with Shanghai, which has not been a purely iron-ore transshipment sea port since the 1990s. However, in the lower Yangtze River, Nantong and Zhenjiang, as transshipment ports, grew steadily in terms of iron ore traffic volume, and some other non-transshipment ports like Suzhou and Jiangyin have also seen a dramatic increase in iron ore throughput since 2002. Thus, it would be interesting to understand what the impact of the transshipment function is on an iron ore port. Moreover, Shanghai used to be the biggest iron ore transshipment port, but with the development of its container trade, its position has been overtaken by Ningbo and Zhoushan. So how does container throughput affect an iron ore transshipment port? With these questions in mind, we propose verifying the following hypotheses:

(1) The iron ore throughput of a port is related to its container throughput.
(2) The transshipment function of a port influences its iron ore throughput.
(3) The transshipment function has a different impact on iron ore traffic at a river port compared to that at a sea port.
(4) Container throughput at an iron ore transshipment port has a different influence on iron ore traffic compared to that at a non-transshipment iron ore port.

Panel data analysis is widely used in investigating the long-term relationship between two "$n$"-dimensional panel data over time. Cullinane et al. (2005; 2006) applied a range of panel data approaches to evaluating the efficiency of container ports. In so doing, the development of the efficiency of each container port in the sample could be tracked over time and across factors like policy, technology and so on. In this study, the development of iron ore traffic in various ports also changed along with time, and was affected by multiple factors, including port function and geographical location. Thus, panel data analysis is considered appropriate to be applied in verifying the above hypotheses.

To verify our hypotheses, a specific panel data model is built as follows:

$$lnOre_{it} = \beta_0 + \beta_1 lnCon_{it} + \beta_2 Trans_{it} + \beta_3 lnCon_{it} * Trans_{it} + u_i + \varepsilon_{it}$$

where $lnOre_{it}$ denotes the natural logarithm of iron ore throughput of port $i$ in year $t$. $lnCon_{it}$ is the natural logarithm of container throughput of port $i$ in year $t$. $Trans_{it}$ is a dummy variable where $Trans_{it}$=1 if the bulk transshipment rate of port *i* in year *t* is over 80% in terms of throughput, otherwise it is equal to 0. $Trans_{it}$ is set to verify the impact of the transshipment function on the iron ore throughput. It is worth noting that whether the port has a transshipment function or not, as revealed by a fluctuant transshipment rate, can be changed.

$lnCon_{it} * Trans_{it}$ as an interaction term is used to test the impact of container throughput on the transshipment function of iron ore ports. $\beta_o$, $\beta_1$, $\beta_2$, $\beta_3$ represent the coefficients, where $\beta_o$ is the constant. $u_i$ and $\varepsilon_{it}$ are the stochastic error terms.

## 4.2 Panel data analysis

The data used in the model is collected from China Ports Yearbook, China Shipping Industry Development Report (2005-2015) and China Compendium of Statistics of Industry, Transportation (1949-1999). From the analysis in Section 3 we know that iron ore shipping traffic along the Yangtze River went through a period of decentralization after 2002, when many new ports and terminals were built following the national port regulation reform. Therefore, for better illustration and comparison purposes, we estimate the panel data of 11 ports from 2002 to 2014 and from 1987 to 2014.

We first conduct the *Levin–Lin–Chu* (LLC) test (Levin et al., 2002) and *Fisher-type ADF* test (Maddala and Wu, 1999) on each panel to test whether there exists unit root. The LLC test makes the simplified assumption that all panels share the same autoregressive parameter, so this test does not allow for the possibility that the throughput of some ports contains unit roots while that of other ports does not. The LLC bias-adjusted test statistic *t* equals -3.4826, which is significantly less than zero ($p=0.0002<0.001$), and the Fisher-type Inverse $\chi^2$ equals 78.0970, which is significantly larger than zero ($p=0.0001<0.001$), so the null hypothesis of a unit root is rejected. The results verify that there is no unit root and that the process is stationary for both container throughput and iron ore throughput.

Another potential problem that needs to be considered is the endogeneity of container throughput as an explanatory variable that might have a simultaneous causality with iron ore throughput. We examine the endogeneity problem by both logical argument and technical measures. In practice, the container throughput of a port may affect the iron ore throughput in two ways. First, the container throughput of a port is strongly related to the regional economic development level (Yang et al., 2014). Regional economic development will lead to an increase in the demand for steel, which may result in a new steel plant being built in the region. Conversely, an increase in a port's iron ore throughput does not necessarily trigger an increase in container throughput. Second, since container throughput can result in greater benefit to the port as well as in further regional economic development, some ports choose to focus more on its container throughput business when it develops into a container transshipment hub, such as Shanghai port did. From the above two points, we assume that container throughput can be an explanatory variable of iron ore throughput, but iron ore throughput can hardly be an explanatory variable of container throughput.

More critically, we examined the endogeneity of container throughput $lnCon_{i,t}$ as an explanatory variable by using the first-lagged container throughput $lnCon_{i,t-1}$ as an instrumental variable ($IV$) to replace $lnCon_{i,t}$ in the regression function, so as to obtain unbiased estimators. The unbiased estimators will be compared with the original estimators obtained through the original fixed effects model using $lnCon_{i,t}$, which are efficient but not certain about biases. We conduct the Durbin-Wu-Hausman test (Davidson and MacKinnon, 1993; Wooldridge, 2010) to examine the endogeneity. This gives test statistics with $p$-values of 0.190 (using sea port data from 1987-2014) and 0.967 (using lower river port data from 1987-2014), which means we cannot reject the hypothesis that there is no systematic difference between the two estimators. Therefore, $lnCon_{i,t}$ is verified as being an exogenous explanatory variable, which is consistent with our argument above.

We then apply the proposed model to the two groups of data, namely, sea ports and lower river ports. Table 5 presents the estimation results. We conduct the Hausman test (Hausman, 1978) and Breusch and Pagan Lagrange multiplier test (Breusch and Pagan, 1980) to verify whether random effects exist. The statistic verifies the preference for a random effect estimator in this case. We can observe that the BP-LM test rejects the existence of random effects except for the data sample of lower river ports during the period 1987-2014. For this data sample, the Hausman statistic is not significant at 5% significance level, which also verifies that the random effects model is preferred over a fixed effects model. The data of all ports during the period of 2002-2014, and sea ports during 1987-2014, are all found to favor a fixed effects model.

The $\beta_1$ is significant at 1% significance level for both groups of data, which implies that the container throughput has a positive and significant effect on the iron ore throughput of the port. The $\beta_2$, $\beta_3$ are not significant at 10% significance level with the data of lower river ports from 1987 to 2014, whereas they are all significant at 5% significance level with data from 2002 to 2014. This indicates that the transshipment function of a port plays a role in affecting the total throughput of a port, but that the effect only began to function in the lower river ports after the port reform in 2002.

Table 5. Estimates of the models, 1987-2014

| **1987-2014** | **Sea** | **Lower River** | **2002-2014** | **Sea** | **Lower River** |
|---|---|---|---|---|---|
| $\beta_1$ | 0.964*** | 1.031*** | $\beta_1$ | 0.485*** | 0.995*** |
| | (14.27) | (12.36) | | (7.85) | (10.12) |
| $\beta_2$ | 6.004*** | 0.967 | $\beta_2$ | 5.646*** | -19.71*** |
| | (4.82) | (0.60) | | (5.01) | (-6.78) |
| $\beta_3$ | -0.464*** | -0.202 | $\beta_3$ | -0.321*** | 1.671*** |
| | (-4.61) | (-1.50) | | (-4.32) | (6.50) |
| $\beta_0$ | -3.301*** | -3.179** | $\beta_0$ | 3.074** | -3.414** |
| | (-3.65) | (-2.81) | | (3.17) | (-2.79) |
| Observations | 97 | 157 | | 52 | 90 |
| R square | 0.731 | 0.404 | | 0.814 | 0.763 |
| F-statistic for FE | 8.56*** | -- | | 24.82*** | 3.72** |
| BP-LM statistic $\chi^2(1)$ | 0.00 | 187.81*** | | 0.00 | 0.73 |
| Hauseman statistic $\chi^2(3)$ | 20.64*** | 7.11* | | 29.92*** | 13.17*** |

Notes: *t*-statistics in parentheses; *** Significant at the 1% level, **at the 5%level, * at the 10% level.

The dummy variable $Trans_{it}$ shows a significant positive effect on the iron ore throughput of sea ports after 2002. This illustrates that the amount of iron ore traffic at an iron ore transshipment sea port is greater than that of a non-transshipment sea port, which explains the fast development of Zhoushan port. In contrast, we found that the dummy variable $Trans_{it}$ also shows a significant negative effect on lower river ports after 2002. This observation has three practical implications. First, it indicates that the decentralized iron ore traffic slowed down the development of the transshipment ports, as most of the non-transshipment ports also operate transshipment cargoes if they have spare capacity. Second, direct transportation to non-transshipment ports is increasing. Third, the transshipment function in the deep lower Yangtze River is in decline. These implications are evidenced by the increasing use of large ships and the fast increase in port throughput in Nantong and Suzhou.

The interaction term $lnCon_{it} * Trans_{it}$ indicates that the container throughput of transshipment sea ports has a significant negative effect on the bulk traffic, whereas that of transshipment river ports has a positive effect compared with non-transshipment river ports. This implies that the function priority at sea ports is continuing, whereas river ports remain in a state of composite development.

From the above model, we found that both the container throughput and the transshipment function affect the iron ore throughput of a port. The transshipment function exerts a positive influence on a sea port but a negative influence on a river port. The container throughput of transshipment sea ports has a negative effect on its bulk traffic, whereas that of transshipment river ports has a positive effect.

## 5 Four forces reshaping bulk port development

From the discussion in the previous two sections, we can summarize the four major forces driving changes to the bulk port system structure, these being: 1) Geographical condition; 2) institutional factors and national policy; 3) industry agglomeration; and 4) changes in market supply and demand along with constantly updating technology.

Geographical condition includes port location and water depth. The appearance of transshipment on the Yangtze River is due to its unique geographical condition, which plays an important role in shaping the shipping network throughout the whole development progress, particularly in stages one, two and five. Generally speaking, ports located at the interface of two different shipping lanes and that have a good water depth condition have the advantage when attracting more traffic. For example, Nanjing is located at the interface of the lower and upper regions of the Yangtze River. Although neighboring ports, such as Zhenjiang and Yangzhou, have a better depth condition than Nanjing, Nanjing always has much more iron ore throughput than these other ports. Similarly, Suzhou and Nantong are located at the mouth of the Yangtze River. Their water-depth condition allows them to accommodate larger capsize bulk ships (20,000 dwt), and during stage five the throughputs of these two ports have dramatically increased.

Institutional factors and national policy also played their part in reshaping the bulk port system during stages one to three, and are the major factors in deciding the handling capacity and development of a port. In stage two, Nanjing and Zhenjiang were specifically chosen as key ports in the downstream section of the Yangtze River, and they thus developed faster than other ports. In stage 4, when all ports were liberalized and handed over to local governments, the driving force for port system development quickly changed to that of the market, causing ports to blossom all along the coastline, followed by a quick decentralization process.

Bulk port development has a strong correlation with the steel industry agglomeration. The development of the bulk port system on the Yangtze River during stages three and four was strongly driven by the steel industry agglomeration. With the dramatic growth of the Chinese economy, the demand for steel increased significantly in stage 3. To catch up with the rising demand, many steel plants or production lines were built alongside the Yangtze River. The giant steel producers in Nanjing, Suzhou and Jiangyin attracted a huge amount of iron ore throughput to the nearby ports. In contrast, the traditional transshipment ports, such as Zhenjiang and Nantong, have not achieved as much growth.

Changes in market supply and demand, together with constantly updating technology, are also related. These exerted their greatest influence on development of the Yangtze River bulk port system during stages four and five. In stage 5, the supply of steel began to exceed the demand for it, the operating profit of the steel industry went down, and shippers were then pressured into reducing the transportation costs. Larger ships were therefore employed, and the one-stop transshipment strategy has since been more widely adopted, which has led to a quick growth in throughput of ports at the mouth of the Yangtze River. At the same time, the transshipment function of river ports in the middle and upstream areas is seen to be on the decline. This is due to ship maximization, and the construction of deep-water terminals in river ports at the mouth of the Yangtze River, such as Suzhou, Nantong and Jiangyin, which now allows larger ships to call at these ports. This technology update has thus changed the structure of the Yangtze River bulk ship system, and represents the future development trends.

In general, these four driving forces functioned either individually or collectively at different development stages, driving development of the bulk port system on the Yangtze River from a sole gateway port system to the current multilayered transshipment port system.

# 6 Conclusion and future prospects

The evolution of a container port system has been broadly addressed by researchers ever since the 1990s, whereas the evolution of a bulk port system has rarely been addressed. This is because the “spot to spot” pattern is broadly adopted in bulk shipping, and almost no transshipment occurs in the middle. However, this is not true for the bulk shipping system along the Yangtze River. Due to its water depth limitation, large sea ships are unable to sail into the Yangtze River. Therefore, since the 1980s, with the dramatic increase in iron ore demand, a multilayered transshipment port system has gradually formed along the Yangtze River. This paper has investigated the evolution of this system.

We have divided the evolution process of the Yangtze River bulk port system into five stages, namely, a sole gateway sea port and scattered river ports (prior to 1984), a dual gateway sea port and double transshipment mode (1998-2002), port concentration (2003-2008), port development and traffic decentralization (2003-2008), and a transportation structure transition (2009-2014). It is found that the evolution of the Yangtze River bulk port system in general follows the theoretical container port system development model.

However, the trends toward the regionalization process observed by Veenstra and Notteboom (2011), and the offshore hub presented by Wang and Ducruet (2012), have not appeared in the development of the bulk port system. The reason for these differences is as follows: First, that inland logistic integration is not necessary for iron ore transportation, since iron ore throughput is related solely to the steel industry. In addition, with the continuous decline in profit for steel manufacturers, iron ore transshipment is moving outward for both sea ports and river ports, and a trend towards transshipment gateway hub centralization seems to be taking place.

From the panel data analysis, we further found that the transshipment function plays different roles in affecting the iron ore throughput of a port. It exerts a positive influence on a sea port but a negative influence on a river port. In addition, the container throughput of transshipment sea ports has a significant negative effect on its bulk traffic, whereas that of transshipment river ports has a positive effect, which suggests that the function priority at sea ports is continuing, whereas the river ports remain on a path of composite development.

Finally, the geographical conditions, institutional factors and national policy, industry agglomeration, and changes in market supply and demand along with technology updates are recognized as being the driving forces behind reshaping the Yangtze River bulk port system. These have functioned either individually or collectively at different development stages.

It is believed that this study will add considerable value to literature on the theoretical port development model, and that it can also be applied to explaining bulk port system development in other regions.

# References


Breusch, T. S., Pagan, A. R., 1980. The Lagrange multiplier test and its applications to model specification in econometrics. The Review of Economic Studies 47 (1), 239-253.

Cullinane, K., Song, D. W., Ji, P., Wang, T. F., 2005. An application of DEA windows analysis to container port production efficiency. Review of Network Economics 3 (2), 184-206.

Cullinane, K. P., Wang, T., 2006. The efficiency of European container ports: A cross-sectional data envelopment analysis. International Journal of Logistics: Research and Applications 9 (1), 19-31.

Davidson, R., Mackinnon, J. 1993. Estimation and inference in econometrics. New York: Oxford University Press.

Hausman, J. A., 1978. Specification tests in econometrics. Econometrica: Journal of the Econometric Society 46 (6), 1251-1271.

Hayuth, Y., 1981. Containerization and the load center concept. Economic Geography 57 (2), 160-176.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K., Haberl, H., Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. Ecological Economics 68 (10), 2696-2705.

Levin, A., Lin, C., Chu, C. J., 2002. Unit root tests in panel data: Asymptotic and finite-sample properties. Journal of Econometrics 108 (1), 1-24.

Liu, L., Wang, K. Y., Yip, T. L., 2013. Development of a container port system in Pearl River Delta: Path to multi-gateway ports. Journal of Transport Geography 28 (2), 30-38.

Loo, B., Hook, B., 2002. Interplay of international, national and local factors in shaping container port development: A case study of Hong Kong. Transport Reviews 22 (2), 219-245.

Maddala, G. S., Wu, S., 1999. A comparative study of unit root tests with panel data and a new simple test. Oxford Bulletin of Economics and Statistics 61 (S1), 631-652.

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., 2010. Concentration and the formation of multi-port gateway regions in the European container port system: An update. Journal of Transport Geography 18 (4), 567-583.

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

Notteboom, T. and Rodrigue, J.P., 2007. Re-assessing port-hinterland relationships in the context of global commodity chains. In: Ports, cities, and global supply chains. London: Ashgate, pp.51-66.

Notteboom, T., 2006. Port regionalization in Antwerp. In: Ports are More Than Piers. Antwerp: De Lloyd. pp.307-328.

Qiu, M., 2008. Coastal port reform in China. Maritime Policy & Management 35 (2), 175-191.

Rhoades, S. A., 1993. The Herfindahl-Hirschman index. Federal Reserve Bulletin 79, 188.

Rodrigue, J. P., Notteboom, T., 2010. Foreland-based regionalization: Integrating intermediate hubs with port hinterlands. Research in Transportation Economics 27 (1), 19-29.

Taaffe, E. J., Morrill, R. L., Gould, P. R., 1963. Transport expansion in underdeveloped countries: A comparative analysis. Geographical Review 53 (4), 503-529.

Veenstra, A., Notteboom, T., 2011. The development of the Yangtze River container port system. Journal of Transport Geography 19 (4), 772-781.

Wang, C., Ducruet, C., 2012. New port development and global city making: Emergence of the Shanghai−Yangshan multilayered gateway hub. Journal of Transport Geography 25 (4), 58-69.

Wang, J.J., Cheng, M. C., 2010. From a hub port city to a global supply chain management center: a case study of Hong Kong. Journal of Transport Geography 18(1), 104-115.

Wang, J. J., 1998. A container load center with a developing hinterland: A case study of Hong Kong. Journal of Transport Geography 6 (3), 187-201.

Wang, J. J., Slack, B., 2000. The evolution of a regional container port system: The Pearl River Delta. Journal of Transport Geography 8 (4), 263-275.

Wilmsmeier, G., Monios, J., 2013. Counterbalancing peripherality and concentration: An analysis of the UK container port system. Maritime Policy & Management 40 (2), 116-132.

Wilmsmeier, G., Monios, J., Pérez-Salas, G., 2014. Port system evolution−the case of Latin America and the Caribbean. Journal of Transport Geography 39 (2), 208-221.

Wooldridge, J. M. 2010. Econometric analysis of cross section and panel data. Cambridge MA: MIT Press.

Yang, D., Chin, A.T.H., Chen, S., 2014. Impact of politics, economic events and port policies on the evolution of maritime traffic in Chinese ports. Maritime Policy & Management 41 (4), 346-366.

Zheng, J., Yang, D., 2016. Hub-and-spoke network design for container shipping along the Yangtze River. Journal of Transport Geography 55 (2), 51-57.