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The development of the Yangtze River container port system

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ABSTRACT

This paper sheds an empirical light on port development patterns by discussing the structure and the development of the Yangtze River ports system. We argue that the Yangtze River system is going through a regionalization phase, mainly in relation to the port of Shanghai. This process started on the lower Yangtze but is now also moving upstream. The transition towards the port regionalization phase is typically a gradual and market-driven process that mirrors the increased focus of market players on logistics integration. This paper builds on the existing literature on port systems and adapts port development models to river ports. Furthermore, we employ some statistical techniques that are common to the analysis of port systems, and introduce some techniques that have not been used much by transport geographers in ports. This paper will address the dynamics in the Yangtze River ports system by analyzing the level of cargo concentration and the degree of inequality in operations of the container ports. The paper also assesses observed differences in development of ports in different areas along the river (upstream/downstream) and reflects on the role of ownership structures in shaping regional load centre networks.

1. Introduction

The Yangtze River plays an important role in the strategy to develop the central and western provinces of China. Previous research (see e.g. Veenstra et al., 2008; Notteboom, 2007; Rimmer and Comtois, 2009) has shown that there is a great potential for growth of especially Yangtze River container shipping. At present, however, the current system of container ports and shipping networks exhibits considerable overcapacity, since the growth of container flows seems to lag behind the growth of the (port) infrastructure and shipping capacity.

This paper aims to investigate the structure and development of the container river port system along the Yangtze. Little is known about these ports, as compared to the Chinese seaports, that have been studied by various authors (see, for instance, Liu et al., 2006; Cullinane et al., 2005), and inland ports in other parts of China and the world, see Wang and Slack (2000) on the Pearl River Delta, Notteboom and Konings (2004) for river ports on the Rhine and Frémont et al. (2009) for river ports in France. Lammie (2008) contains much in terms of descriptive information on the Yangtze River Ports, but very little analysis has been presented to date.

Some of the main questions that deserve answers concerning the Yangtze River ports are: what is the level of concentration in the Yangtze container port system, and what is the degree of inequality between the container river ports? Are there differences in development of ports in different areas along the river (upstream/downstream) and does the type of ownership play a role?

This paper builds on the existing literature on port systems and adapts port development models to river ports. Furthermore, we employ some statistical techniques that are common to the analysis of port systems, and introduce several techniques that have not been used much by transport geographers in the analysis of port systems.

The paper is organized as follows. We first introduce the most relevant characteristics of the port system along the Yangtze River. We then develop the analytical framework for an inland port system. Subsequently, we present the analysis of concentration (Section 4), cluster analysis (Section 5), and the investigation of the role of outside ownership (Section 6). We finish with our conclusions.

2. The Yangtze River

2.1. Situation plan of the Yangtze River

Fig. 1 shows the position of the Yangtze River in China. The total length of the Yangtze River is about 6300 km. About 2800 km of that is navigable for cargo vessels. This part of the river can be divided into three main reaches: the lower reach from Shanghai to Nanjing, the middle reach from Nanjing to Yichang (the container port that is nearest to the Three Gorges Dam) and the upper

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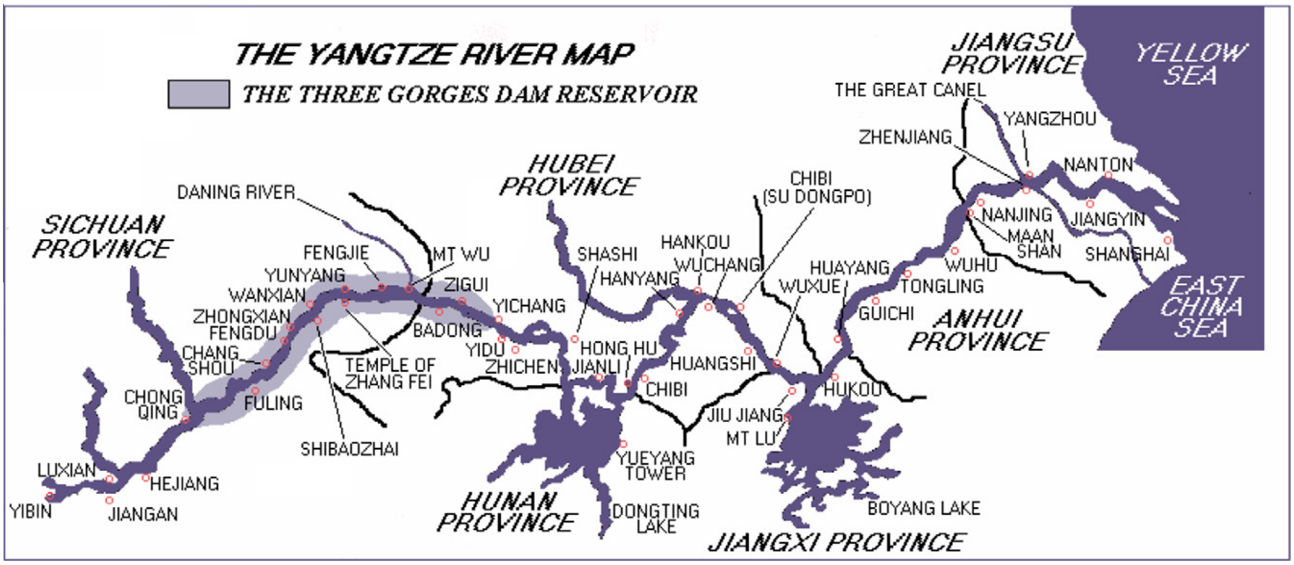

Fig. 1. Map of the Yangtze River. *Source*: ©Solid Software Pty., Ltd. (permission to use this map was kindly granted by Solid Software Pty., Ltd., Australia).

reach from Yichang to Yibin. The inland port city of Chongqing is located in the upper reach, and the city of Wuhan is located in the middle reach. Together with Nanjing and Shanghai, these four cities are the main cities along the Yangtze River. The river depth develops from 10.5 m in the delta area between Shanghai and Nanjing, around 5–6 m between Wuhu and Wuhan, about 4 m in the stretch between Fuling and Wuhan, to 2.5–3 m around Chongqing and less than 2 m beyond Lanjiatuo (which lies between Chongqing and Luzhou) (these are average winter figures, Changjiang Waterway Bureau, 2007). The water level between winter and summer can differ as much as 4 m on average, with much larger fluctuations around the average.

2.2. Port overview

An overview of the throughput of the main container ports along the Yangtze River is presented in Table 1. The river is characterized by a combination of large ports and very small ports. Some of the ports show substantial growth, while other river ports grow very little, or even decline somewhat. The latter are mostly small ports (e.g. Anqing Wulimiao) or ports that are being replaced by more modern facilities (e.g. Chongqing Jiulongpo, Nanjing International Container Terminal).

From Table 1, it is clear that the bigger ports are all located in the lower reach. These ports facilitate the economic development that is still concentrated in the area around Shanghai, and these ports can receive coastal and deepsea vessels, which leads to much more traffic and growth opportunities than the upper and middle reach ports.

Another observation that can be made is the concentration of relatively small ports in the middle reach: Chenglingji, Huangshi, Anqing, Tongling, Maanshan. Including Chizhou, four of these are in Anhui province, which is one of the poorer provinces of China. The weak position of Anhui on the international market (in sharp contrast to coastal provinces such as Zhejiang and Jiangsu) apparently reflects on the development of its container ports. Another reason is the apparent inability of the Anhui Provincial Government to control the development of port capacity and to concentrate on one large port (Wuhu).[2] The reason that was given for this is that cities can apply directly to the national government for approval to develop a port. The provincial government has little influence in this process.

Table 1 also contains information on the ownership of the ports/terminals. In principle, from the mid-1980s, the ports were all owned by municipal authorities. Fairly quickly outside investors were attracted to ports in Wuhan (Wuhan Yangluo) in the 1980s and Changshu in 1994 (Lammie, 2008). Later many more ports and terminals attracted primarily Chinese investors, among them the Shanghai port operator SIPG (Shanghai International Port Group) and container shipping line COSCO. Ignoring the ports and terminals that are merely stock listed, in total 60% of the ports have outside ownership, representing 84% of total throughput. From this, one could infer outside investors seem to be attracted to the bigger terminals. This will be investigated in greater detail in a next section.

It should be mentioned that throughput data on ports in China is notoriously unreliable. Reporting of throughput is not standardized, and some ports report throughput including empties, while other do not, and ports sometimes are not clear if they report containers or TEU. In addition, ports may consist of different container handling companies, some of which do not have a fixed association with a terminal. They hire space whenever there is a ship to handle, and this might be in a container terminal or in a general cargo or break bulk terminal. As a result, handling figures based on terminals or handling companies may not add up to a port's total container throughput. In Shanghai, for instance, this gap may be as much as one million containers.

In addition to throughput, capacity information is also available on most container terminals. This information is even less reliable than throughput information: for the larger ports (e.g. Nanjing and Taicang) two or more very different capacity figures circulate in public sources. As an illustration, Fig. 2 reports a comparison of cumulative capacity and throughput along the river. From the figure, it is clear that there is sufficient room for growth in all ports, and that Nanjing is one of the ports that is operating relatively close to capacity. Nanjing does have extensive expansion plans, as do almost all the other ports. Due to the unreliability of this data, we will not use it further in our analysis.

We also present an overview of some of the technical dimensions of the container terminals along the Yangtze River. For all ports in Table 1, we have collected the number of cranes, the

[2] Personal communication with Anhui NDRC representatives during an inspection trip on Yangtze River inland shipping, June 2007.

Table 1
Port throughput 2005–2007 (in TEU); in order of location along the river.

	Outside ownership	2005	2005	2007
Upper reach				
Luzhou Port		21,500	38,287	60,776
Chongqing Jiulongpo	Listed	170,100	180,000	200,000
Chongqing Cuntan	ph1: SIPG		75,254	184,535
Wanzhou Hongxigou Intern.container terminal		10,500	13,000	15,798
Fuling Container terminal		11,800	29,105	38,786
Middle reach				
Jingzhou Yanka terminal	SIPG (m)	22,308	38,883	51,350
Chenglingji Songyanghu New terminal		68,000	43,405	33,016
Wuhan Yangsi container terminal	SIPG	178,100	133,956	159,048
Wuhan Yangluo terminal	CIG	65,000	107,384	150,338
Huangshi Foreign trade terminal extention		5400	11,258	14,429
Jiujiang Longkaihe terminal	SIPG	46,200	73,789	82,346
Anqing Wulimiao terminal		7500	8996	8866
Tongling Henggang terminal		1500	4002	18,506
Wuhu Zhujiaqiao foreign trade terminal	listed	64,200	100,167	162,519
Ma'anshan Old terminal		37,100	48,209	30,993
Lower reach				
Nanjing Longtan container terminal	SIPG, COSCO	178,686	685,600	913,414
Nanjing International container terminal		262,263	53,516	164,096
Zhenjiang Dagang terminal	SDIC, COSCO?	177,000	139,031	80,000
Zhenjiang Longmen terminal	COSCO?			110,665
Yangzhou Yuanyang Intern. terminal	COSCO	157,000	222,912	167,299
Taizhou Gaogang container terminal		39,000	54,999	64,416
Changzhou Yutang terminal	Jialian hold. (m)	33,200	39,000	22,095
Jiangyin East terminal	SIPG (m)	48,600	64,491	40,865
Jiangyin Sunan Container terminal	SIPG (m)		60,116	192,000
Zhangjiagang Yongjia container terminal	COSCO	377,100	455,946	589,547
Nantong Langshan terminal	PYI	267,000	353,859	395,513
Changshu Xinghua terminal	MIIF/panunited	110,000	107,770	131,953
Taicang International container terminal	MT	250,900	601,221	1068,097

Source: Lammie (2008), port and terminal websites, various internet sources, personal communication. '(m)' = minority stake, 'ph1' is phase 1.

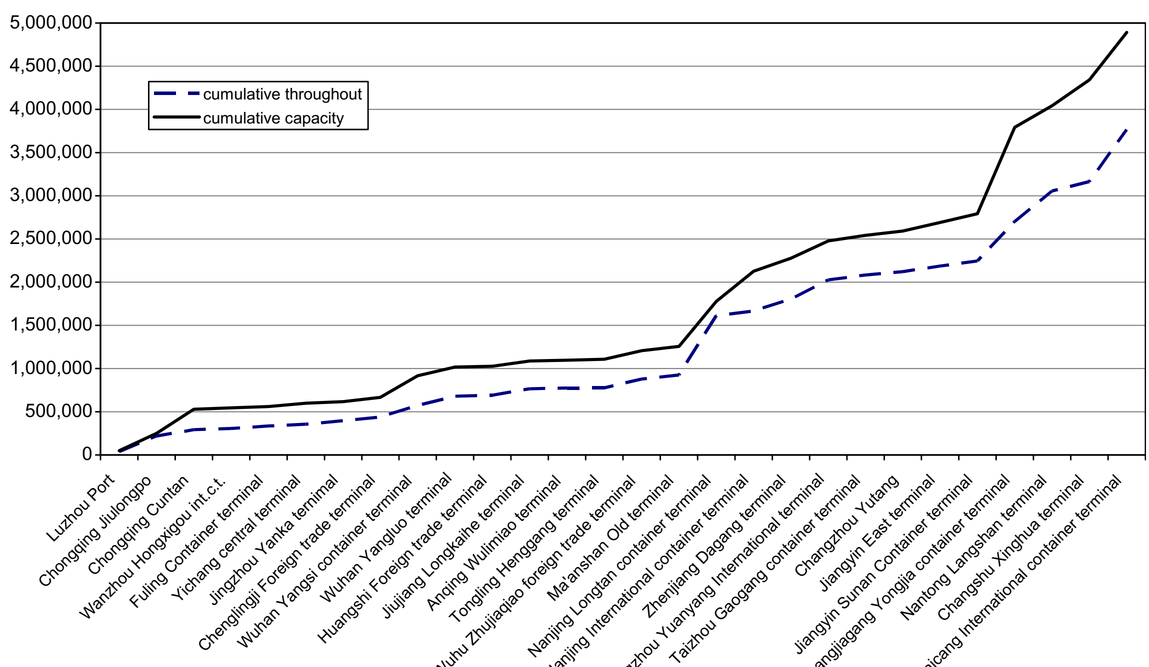

Fig. 2. Capacity-throughput comparison 2006. *Source*: Authors' compilation.

number of berths, the area of the stacking yard, the maximum depth at the quay, maximum size of ships at berth and quay length. This data appears in Table 2. We define berthing capacity as the product of the maximum depth at the quay and the maximum size of ships at berth. This reduces the number of variables by one, which is desirable due to the limited number of terminals in our sample. Data for these variables, and design capacity for all terminals, were collected for the period 2005–2010. The development plans of the terminals are all fairly well documented, and expansion of equipment and terminal dimensions can be found from

Table 2
Average operational characteristics (unless otherwise indicated).

	Cranes (avg. #)	Berths (avg. #)	Yard (avg. m^2)	Berthing cap (avg. TEU)	Quay (avg. m)	No. of terminals	Total throughput (TEU)
2005	3.23	1.58	53,500	124,269	393	26	2905,506
2006	3.54	1.79	61,732	125,214	429	28	4264,759
2007	3.75	1.93	75,466	134,862	480	29	5748,389
2008	4.57	2.23	97,694	142,032	604	31	6723,513
2009	4.55	2.29	97,952	138,844	610	32	7742,815
2010	5.81	2.69	154,731	138,844	687	32	8904,237

Note: 2008–2010 figures are based on reported expansion projects. # Stands for number, m is meter, m^2 is square meter, TEU is 20 foot equivalent unit.

the terminals themselves or other (Chinese) data sources. We have also estimated throughput for the period 2007–2010. These estimates are based on terminals' own projections. Compared to growth rates in the past, this is a conservative estimate, although growth rates overall were declining.

The development of the average operational characteristics, as presented in Table 2, gives an impression of the dynamics of port development along the Yangtze River. Ports are getting bigger in terms of the number of cranes, number of berths, yard capacity and quay length. The year 2009, however, seems to represent a temporary slowdown in port development. In fact the only new ports in 2009 are the replacement of the old container port of Chenglingji by the new Songyanghu terminal, and the new but small Tongling container terminal. Berthing capacity in 2010 is not growing because it is calculated by multiplying maximum depth at the quay with maximum ship size. This measure increased primarily due to the addition of new terminals before 2010. In 2010, no new terminals were added. In 2010, the new Wuhu Cherry car and container terminal is planned to start operations, but on this terminal no operational information was available.

Finally, it is worthwhile to analyze the liner service networks on the Yangtze River. The river services are primarily organized per navigation area (upper, middle and lower stretches), see Notteboom (2007). Line-bundling types of services are dominant with each service typically calling at three to four inland ports per rotation. Even in the load centre of Nanjing, end-to-end services represent less than one-third of all river services calling at the Lower Yangtze inland port. In other inland ports, line-bundling services have a market share of more than 80%. The only exceptions are found in the Upper Yangtze. End-to-end services are rare in the Middle Yangtze segment. There are no hub-and-spoke structures for container transport in place on the Yangtze, although the market might be evolving towards large inland waterway hubs on the Lower Yangtze (particularly Nanjing and Taicang) with direct feeder connections to major transshipment hubs in East Asia such as Busan in South Korea and Shanghai's Yangshan offshore terminal complex situated northeast of Hangzhou Bay.

3. The analysis of an inland port system: conceptual framework and hypotheses

A well-established body of literature exists on the development of seaport systems. A central theme to the study of port systems is the level of spatial and functional concentration and the analysis of the underlying factors that contribute to such concentration. Seminal papers on this issue include Ogundana (1970) and Taaffe et al. (1963) which portray an evolutionary pattern from scattered, poorly connected ports along the coastline to a main network consisting of corridors between gateway ports and major hinterland centres. Barke (1986) and Hayuth (1981) refer to rising pressures for deconcentration in port systems. Empirical research has demonstrated that some port systems and port ranges are getting more spatially concentrated while others are evolving to a more evenly distributed system, see e.g. Kuby and Reid (1992), Notteboom (1997, 2006), McCalla (1999), Lago et al. (2001), Rimmer and Comtois (2009) and Notteboom (2010).

Notteboom and Rodrigue (2005) have added an additional phase to port development: the regionalization phase which links seaport system development to the development of inland ports and centres. The phase of regionalization takes the process of port development beyond the perimeter of the port and culminates in the development of regional load centre networks between seaports and inland ports. Port regionalization is thus strongly interrelated with the development and performance of associated inland networks that give access to cargo bases in the hinterland.

The link between the structure and the development of the Yangtze River port system with the models on seaport system development is relevant for three reasons.

First of all, we argue that the Yangtze River port system is affected by (de)concentration patterns at the side of the seaport system which feeds the river system with container cargo. Cargo growth in the seaport system obviously puts more pressure on hinterland networks. These hinterland networks adapt through corridor development. The combination of large deepsea volumes and massive intermodal corridors allows load centres to enlarge contestable hinterland areas, to create discontinuous hinterland areas and to intrude in the natural hinterland of rival ports (the so-called 'island' formation, see also Notteboom and Rodrigue, 2005). A river port system is to be considered as a corridor consisting of a set of continuous and discontinuous areas all positioned along a river or waterway (Fig. 3). However, the Yangtze River case is much more complex than suggested by the generic conceptual model in Fig. 3. On the one hand, the development of the offshore port of Yangshan, also managed by Shanghai, has triggered the development of feeder services between the Yangshan terminal complex and container terminals in Shanghai and Nanjing. On the other hand, while Shanghai is the main gateway feeding the container river port system along the Yangtze, there are other liner service configurations in place that bypass Shanghai/Yangshan. For example, Taicang in Jiangsu province has developed strong links to Busan, the most important transhipment hub in the Northeast Asia with a container volume of 13.4 million TEU in 2008 (compared to 28 million TEU for Shanghai). Taicang in this way competes with the pivotal role of Shanghai. These examples support the concept of 'foreland-based regionalization' as developed by Rodrigue and Notteboom (2010).

Secondly, we argue that the Yangtze River system is affected by a regionalization phase, mainly, but not exclusively, in relation to the port of Shanghai. This process started on the lower Yangtze but is now moving upstream. The transition towards the port regionalization phase is typically a gradual and market-driven process that mirrors the increased focus of market players on logistics network integration. As we will demonstrate later in this paper, the inland strategy of terminal operator SIPG (Shanghai International Port Group) proved to be instrumental for the observed regionalization and the associated creation of a regional load centre network in relation to the port of Shanghai.

Thirdly, it is interesting to analyze whether the concentration mechanisms, observed in seaport systems, also work in a similar

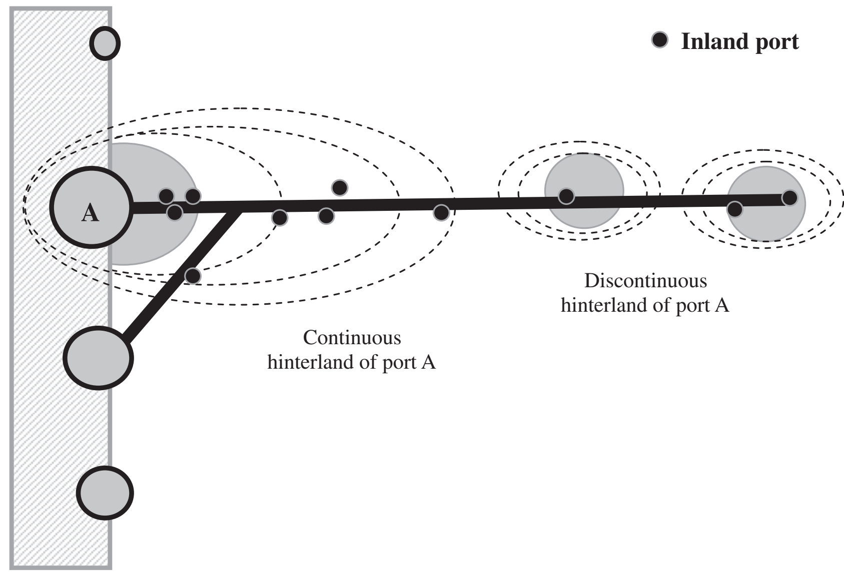

Fig. 3. A river port system connected to a seaport system. *Source*: Adapted from Notteboom and Rodrigue (2005).

way in river port systems. We argue that the concentration patterns in river port systems do not necessarily follow the same principles as in seaport systems. A first difference between river port systems and seaport systems lies in the interconnection with other nodes in the wider network. Seaports are connected to a large set of overseas seaports, while inland port systems are typically fed by only a few large gateway ports. For example, the Rhine river in Europe is highly dependent on the main container ports Rotterdam and Antwerp (see Notteboom and Konings, 2004), the Seine river ports in France rely primarily on maritime container flows transshipped in Le Havre and the ports in the Rhône/Saône basin such as Lyon and Dijon are highly dependent on the Mediterranean seaport of Marseille (see Frémont et al., 2009). Similarly the Yangtze River port system relies mainly on Shanghai and to a lesser extent also on Ningbo and the connections of the lower reach ports (Taicang, Nanjing, Ziangjiagang, among others), with nearby countries such as South Korea and Japan, for containerized cargo volumes. A second difference between river port systems and seaport systems lies in the spatial structure. The container flows on the Yangtze River have a treelike structure with limited or no lateral connections between the branches. Furthermore, the nautical accessibility of inland ports gradually diminishes towards the upstream ports, while the vessel capacity is restricted and the fleet is not very homogeneous. Because of the deep water conditions in the lower reaches and the shipping connections with nearby countries, vessels plying the lower reaches are often short sea vessels. These short sea ships typically have higher unit costs than the inland vessels used on the Yangtze due to their elevated capital costs, higher bunker costs per load unit and more strict manning requirements. These elements favour the use of line-bundling systems and make hub-and-spoke service networks less obvious. In a seaport system, neighbouring ports sharing the same coastline can have largely different draft profiles. As a result, a port with a favourable draft can potentially become bigger then adjacent ports simply because the port can accommodate larger vessels (concentration). In an inland port system, it is more likely that adjacent ports will have a similar draft profile. Thus, differences in nautical access generally do not play a decisive role as drivers for cargo concentration at a local level (i.e. among adjacent inland ports in the same navigation area).

From the theoretical models and the adapted model in Fig. 3, and the observations on the Yangtze River port system in Section 2, we formulate several hypotheses about the likely level of concentration one might find in the data:

1. There is concentration of port traffic in the Yangtze River port system.
2. The concentration changes over time.
3. The concentration of port activity is characterized by clustering or agglomeration of large ports in economically strong areas and agglomeration of weak ports in economically weak areas.
4. The ports can be clustered on the basis of operational variables.
5. The ports can be clustered on the basis of economic variables.
6. The ports can be clustered on the basis of distance to Shanghai.
7. Outside ownership of the terminals impacts the operational lay out and performance of the ports.

This analysis will serve to expand the theoretical port development models in one more way: they will show that inland ports follow a similar pattern of development as seaports. Especially the test of the fifth hypothesis will confirm or contradict this.

4. Concentration analysis

4.1. Measures of concentration

We investigate the above hypotheses by calculating various dispersion and concentration measures. Ducruet et al. (2009) identified 34 academic studies on port system concentration published between 1963 and 2008. From this study, it appears quite common to use the Gini inequality index in studies on port concentration. In this paper, we will use the following formula for the Gini coefficient:

$$G = 1 - \sum_{k=1}^{N}(X_k - X_{k-1})(Y_k + Y_{k+1}), \tag{1}$$

where the X_k and the Y_k are the cumulative proportion of the number of ports and the cumulative proportion of the throughput in the ports, respectively. The Gini coefficient requires ordering the data by throughput volume. The Gini coefficient value lies between 0 and 1, with 0 indicating complete equality and 1 complete inequality.

According to Giles (2004), Eq. (1) is equivalent with a calculation of the Gini coefficient based on the artificial regression equation:

$$i\sqrt{y_i} = \theta\sqrt{y_i} + u_i, \tag{2}$$

where G is then calculated as $\frac{2\hat{\theta}}{n} - 1 - \frac{1}{n}$ in (2), y_i is the ratio of throughput to total throughput of the ith port, i is a trend vector. This method allows for the testing of Gini coefficients by including two ordered data sets in a seemingly unrelated regression (SUR) framework, and testing for equality of the two θs by means of a Wald test (see Parola and Veenstra (2008) for an example of this testing procedure in ports).

The Gini coefficient has its merits, but it remains a descriptive measure, not an explanatory one. The Gini coefficient itself can be deployed as a source for a better understanding of the spatial dynamics in port systems through a Gini decomposition analysis (see Notteboom (2006) for a full discussion on the methodology). However, this technique requires a large set of objects/ports and the creation of sub-groups within the overall group of subjects. An application of the Gini decomposition analysis to the Yangtze River is not feasible given the relatively small number of inland ports along the Yangtze River, particularly when considering potential sub-groups (lower, middle and upper Yangtze).

The Gini coefficient has a number of other drawbacks, such as small sample bias (Deltas, 2003), sensitivity to ordering (Cowell, 1988) and sensitivity to data errors. To circumvent some of these problems, we will also use entropy-based indices such as Theil Entropy and a derived measure called Symmetric Redundancy. We will also report the adjusted Gini (Deltas, 2003), which is $n/(n-1)^{*}G$, where n is the size of the sample.

Entropy is a measure of disorder in a system. In an economic context, high entropy or high disorder equals equality in the system. Redundancy is the difference between maximum entropy and the entropy of the system. The indices we introduce below are in fact redundancy indices. We use the Theil-T and Theil-L redundancies that is computed as follows:

$$T_T = \sum_{i=1}^{N}\left(\frac{x_i}{\bar{x}}\ln\left(\frac{x_i}{\bar{x}}\right)\right) \quad \text{and} \quad T_L = \sum_{i=1}^{N}\ln\left(\frac{\bar{x}}{x_i}\right), \tag{3}$$

where N is the total number of ports in the sample, x_i is the throughput of the ith port and $\bar{x}$ is the average throughput. The Theil indices range between 0 and ln(N). A normalized value of the Theil index T can be obtained as $1 - e^{-T}$. This value ranges between 0 and 1.

Given that both Theil indices are not symmetric, a symmetric redundancy SR can be calculated as:

$$S_R = (T_T + T_L)/2 \tag{4}$$

We can compute these measures over several years to see how they develop and if concentration or deconcentration processes are taking place.

In addition to the concentration analysis of throughput, we are also interested in the spatial distribution of the ports along the river. This spatial dimension is not often taken into account in the empirical research on port systems. Here the abovementioned measures cannot help us, because the Gini coefficient requires ordering (which does not preserve the order of the ports along the river) and the Theil redundancy measures are invariant to ordering.

One solution is to apply the Gini coefficient to the cumulative throughput along the river. This cumulative throughput is an ordered variable because port throughput is always positive. However, the resulting Gini coefficient then refers to the smoothness of the cumulative throughput, and not to the concentration of ports.

A first approach is to use the reflexive nearest neighbour analysis that was initially applied by Dacey (1960) for the spacing of river towns along the Mississippi. In this analysis the distance between pairs of towns or ports can be used to determine if the spacing is either random, grouped (there are clusters of ports), or equidistant. The reference probabilities that ports A and B are each other's first, second or third order nearest neighbour are derived from Cox (1981). If the calculated probabilities are equal, lower or higher than these reference probabilities, then the ports are randomly distributed, relatively grouped or uniformly spaced along the river, respectively.

Another possible measure is Moran's I statistic to measure global spatial autocorrelation. It is calculated as

$$I = \frac{N}{S_0}\frac{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{N}(x_i - \bar{x})^2}, \tag{5}$$

where N is the size of the sample, w_{ij} is the spatial weight matrix indicating the geographical relationship between regions along the river, S_0 is the sum of all the w_{ij}, and x_i is the ith ports' throughput. Negative (positive) values indicate negative (positive) spatial autocorrelation. The standard deviation and mean of I are known and can be calculated. On the basis of these metrics, a test for statistical significance of I can be carried out. If I shows positive spatial autocorrelation, then there is agglomeration of ports, with large ports being located close to other large ports.

Thirdly, we consider various ways of grouping the ports to test Hypotheses 4–6. For this purpose, we will use cluster analysis. A cluster is homogeneous with respect to some characteristics and different from other clusters (Sharma, 1996). We use hierarchical clustering following Ward's method. Ward's method finds clusters by optimizing within-cluster homogeneity, as measured by the within-cluster sum of squares, see for details Sharma (1996, chapter 7). The cluster validity is verified by multivariate analysis of variance methods.

Finally, we aim to analyze the impact of outside ownership on the performance and structure of the terminals (Hypothesis 7). For this purpose we use univariate and multivariate analysis of variance methods (see Berenson et al. (2002) and Sharma (1996) for details). The univariate and multivariate analysis of variance methods will allow the identification of operational characteristics of the terminals that discriminate different types of ownership.

4.2. Empirical results

Our sample of throughput data on the Yangtze Ports covers the period 2002–2010. The last 3 years of this period are estimates. The number of terminals in this period doubles from 16 to 32. In addition, we collected GDP and population information for all cities in which terminals are located from the China Cities Statistical Yearbook 2006 (data for 2005). In some cases (Fuling, Wanzhou) the cities statistical yearbook did not contain information, and internet sources, such as the city of city region promotional websites, were used to supplement the data set. The cities Zhangjiagang, Taicang and Changshu are all part of the city conglomerate of Suzhou. For these cities, the Suzhou economic promotion website supplied the GDP and population figures. In all cases, we used GDP and population for the metropolitan region. For Chongqing, this includes the entire metropolitan area.

GDP and population figures were used as rough proxies of the relative importance of hinterland regions. We are aware that the relationship between GDP or population with the river port container throughputs along the Yangtze River may be seriously skewed statistically due to the different containerisation rates along the river. The containerisation rate typically declines with the inland distance partly because of the strong link between containerised cargo and export flows in China. On the other hand, one could argue that there is a direct relationship between GDP and

Table 3
Concentration indicators Yangtze River container terminals.

	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gini	0.653	0.652	0.607	0.553	0.582	0.585	0.589	0.601	0.602
Gini adj.	0.612	0.621	0.580	0.532	0.561	0.565	0.570	0.582	0.583
Theil *T*	0.776	0.764	0.646	0.523	0.588	0.603	0.618	0.644	0.645
Theil *T* norm	0.540	0.534	0.476	0.407	0.445	0.453	0.461	0.475	0.476
Symm.Red.	1.000	0.969	0.784	0.640	0.665	0.669	0.681	0.717	0.718

Note: Adj. is adjusted, norm is normalized, Symm.Red. is symmetric redundancy.

exports. For example, in Anhui province, GDP is low largely because of a lack of exports.

The calculation of Gini coefficients, Theil redundancies and symmetric redundancy is reported in Table 3 and depicted in Fig. 4.

Observe from Table 3 and Fig. 4, that the port throughput in the Yangtze River port system is relatively concentrated. Observe further that all measures decline towards 2005 and then increase again. The increase, however, is not very substantial: a Wald test on the equality of the Gini coefficients of 2005 compared to 2007 is rejected ($\chi^2 = 0.69$, $p = 0.40$). Furthermore, the flattening out in 2008–2010 reflects the identical growth percentages that were used to forecast the throughput figures. The developments in the years 2004 and 2005 apparently flattened the throughput distribution due to the opening of a substantial number of new terminals. In later years (2006 and 2007), fewer terminals were opened, and existing terminals grew. This will most likely increase concentration of throughput, but the data currently does not support this.

From this analysis, it is clear that the Yangtze container terminals are still in an early phase of development. They are in such an early stage, in fact, that their current development does not correspond to the earlier models of port system development as presented by Taaffe et al. (1963) and Hayuth (1981). These models all begin with a relatively equal distribution of ports followed by a phase of cargo concentration. The Yangtze port system does not seem to have reached the end of the initial setting of terminals. The insertion of new cargo handling centres triggers a deconcentration tendency, which in later stages might shift to concentration as observed in more mature port systems. The analysis so far confirms Hypothesis 1 and 2.

In addition to the general concentration of throughput, we also analyze the geographical clustering or agglomeration of ports. We present the reflexive nearest neighbour analysis in Table 4. Distances were obtained from the maritime routing calculator Netpas (www.netpas.net). This distance calculator gives distances between cities. Therefore, cases with two terminals in one city were reduced to one location in our calculations. This is the case for Chongqing, Wuhan, Nanjing and Jiujiang. The total number of cities/ports included in the analysis was therefore 25.

From the table, we can see that the spacing of ports along the Yangtze River as a whole is relatively grouped. If we look at the three sub-regions, it is clear that this outcome originates mainly from the upper and lower reach. The ports in the middle reach are spaced randomly.

We also calculate Moran's I statistic with a weight matrix whose elements equal 1 if two ports are adjacent, and are 0 elsewhere.

The values of Moran's I statistic and the corresponding standard deviation, presented in Table 5, indicate that only for the year 2005 there is significant global spatial autocorrelation. This autocorrelation is positive, which means that a large port tends to be adjacent to another large port, and small ports to small ports. We argue that this is partly the result of the treelike structure of the Yangtze River system and the decreasing navigability of the upstream sections of the river. It is also a result of the distribution of economic activity along the Yangtze River, with large export-oriented economic centres in the lower Yangtze (e.g. Shanghai, Wuxi and Nanjing) and less export-oriented centres (and thus lower volumes) in the upper reaches of the river (cf. Chongqing and Wuhan).

The spatial analysis amends the picture of the relative concentration that was found on the basis of the Gini and Theil indices. While the size distribution of the ports is relatively unequal, the spatial concentration of port operations is not very strong. This fact that the spatial throughput distribution of the ports is less concentrated than the size distribution, is confirmed by calculating the Gini coefficients for the cumulative throughput along the river. For 2005, 2006, and 2007, these coefficients (adjusted) are 0.405,

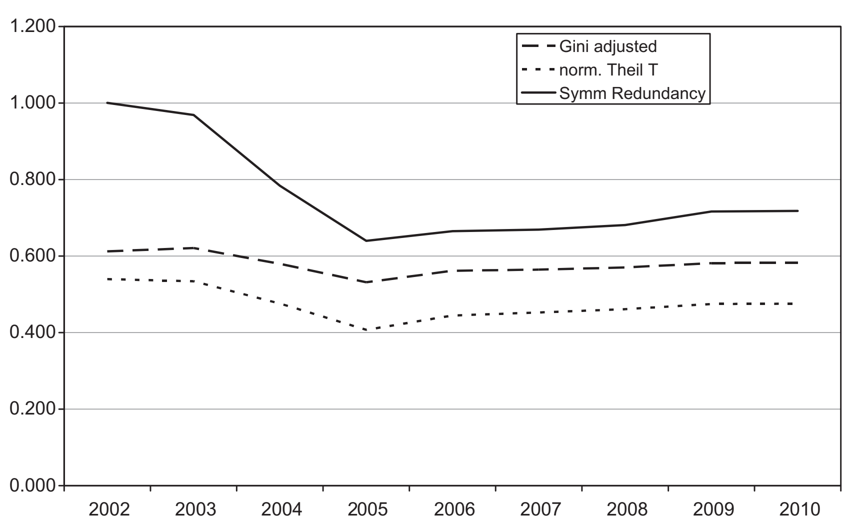

Fig. 4. Selected concentration measures.

Table 4
Reflexive nearest neighbour analysis.

	No. of ports	First order nearest neighbours	Second order nearest neighbours	Third order nearest neighbours
Yangtze River	25	13 (0.520)	8 (0.320)	6 (0.240)
Upper reach	5	3 (0.60)	2 (0.40)	1 (0.20)
Middle reach	11	7 (0.636)	2 (0.182)	4 (0.364)
Lower reach	11	6 (0.545)	4 (0.364)	2 (0.182)
Reference probabilities		0.667	0.370	0.271

Note: Calculated probabilities are in brackets. Reference probabilities are due to Cox (1981) for the one dimensional case ($k = 1$). Distances between the port pairs are obtained from maritime routing calculator Netpas Distance 2.5 (www.netpas.net). For the three sub-regions along the river, the boundary ports (Yichang and Nanjing) were included in both regions.

Table 5
Spatial clustering of ports along the Yangtze river.

	Number of ports			Moran's I
	Upper reach	Middle reach	Lower reach	
Length (km)	1044	1359	418	
2005	4	11	11	0.373*
2006	5	11	12	0.052
2007	5	11	13	0.138
2010	5	13	13	0.151

* Indicates statistical significance at 5%.

0.395 and 0.396, respectively. These values are markedly lower than the Gini coefficients for the size distribution. But note also that the Gini coefficient as applied to the cumulative throughput distribution does not pick up the change in spatial autocorrelation, even though these values are not statistically significant.

We take these results to imply that the fact that the container ports are located along a river, with its specific geographical structure and accessibility characteristics and containerisation rate potential, limits their development compared to seaports. The specific location of the port in the upper, middle or lower reach further determines its growth potential. In other words, even in large urban agglomerations in the upper and middle reaches, the ports will never attain the same size as in the smaller urban agglomerations in the lower reach. This degree of bounded development is not present in the current port development models.

5. Cluster analysis

In this section, we consider various ways of grouping the inland ports along the Yangtze river to test Hypotheses 4–6. We use the following variables for clustering (all for 2005/2006):

- Operational variables of the inland ports, including the number of cranes, the yard capacity, the number of berths, the quay length and total container throughput.
- Economic variables, including GDP and population of the surrounding regions.
- Geographic variables, including the distance to Shanghai and the berthing capacity.

We have excluded throughput growth rate as a variable because it shows some exceptional values, among others due to the opening of Nanjing Longtan. Terminal capacity is also excluded because this variable is thought to be too unreliable. We have grouped berthing capacity as a geographic variable, because it contains information on the depth of the river as it develops along the river. GDP and population in areas that have two terminals (Chongqing, Wuhan) are distributed proportional to terminal throughput.

We perform the clustering procedure as follows: we first transform the variables involved to z-scores (which have zero mean and a standard deviation equal to 1). We then perform a hierarchical clustering using Ward's method. We select the number of clusters based on the following criteria: (1) clusters should account for more than 5% of the total cases, (2) a solution that explains 70% or more of the measures being clustered (measured by partial eta squared η_p), (3) a solution that explains 99% or more of the variance in the joint distribution (measured by $1 - \text{Wilk's } \Lambda$) and (4) the interpretability of the solution.

The clustering that results from the operational variables gives four clusters, one of which contains Nanjing Longtan terminal, Zhangjiagang, Nantong and Taicang (the four biggest terminals) and one Jiangyin east and Changshu (small lower reach terminals with very long quays), one the Chongqing terminals, Nanjing Longtan and Jiangyin Sunan terminal, and the fourth all the other terminals. The ports in the lower reach are split over at least three clusters. This is an indication that the terminals in the lower reach, from an operational perspective, are definitely not a homogeneous set of terminals.

The grouping based on economic variables does not meet our first stopping criterion, because whatever the number of clusters, the part of the Chongqing municipality associated with the Jiulongpo terminal remains a cluster on its own. The selection of four clusters seems to be the most optimal clustering, with one cluster containing the large economic centres represented by Wuhan Yangsi terminal, Nanjing International container terminal, Changzhou Yutang terminal, and Nantong container terminal, one cluster contains mainly the smaller terminals in economically smaller areas and one cluster containing the remaining terminals.

The grouping on the basis of geographical variables leads to three clusters, that almost coincides with the division in upper, middle and lower reach. The division between the first and second cluster is between Wanzhou and Yichang, and the division between the second and the third cluster is between Ma'anshan and Nanjing. However, the second cluster also contains the smaller terminals in the lower reach: Changzhou Yutang, Jiangyin East and Changshu Xinghua terminals. These three terminals have a markedly lower berthing capacity than the surrounding terminals in the lower reach, which is why they apparently fit better in the second cluster.

Note that the clustering based on these three categories of variables leads to three very different groupings of the terminals. Selecting one variable from each of the three categories leads to the clustering reported in the last row of Table 6. The three clusters contain (1) Chongqing, Wuhan Yangsi, Nanjing International, Changzhou and Nantong (the five largest areas by GDP), (2) Nanjing Longtan, Zhanjiagang and Taicang (the three largest terminals) and (3) the rest. We interpret the fact that these clusters are spread out along the river as support for the finding in the previous section that there is limited geographical agglomeration of ports.

6. The impact of outside ownership

Table 1 contained information on outside investors in the various terminals along the Yangtze River. Dominant investors are the Shanghai based SIPG and COSCO, but a number of other investors are also present: Modern Terminals, China Infrastructure Group (Hong Kong), PYI (Singapore) and MIIF (Australia).

The position of SIPG is particularly interesting. Before 2003, the port of Shanghai was run by a combined authority-operator entity called the Shanghai Port Authority. This entity was subsequently split in the Shanghai Municipal Port Administration Bureau – the authority and SIPG – the operator. This has created a unique relationship between port authority and operator, which differs from the typical situation in many landlord ports, where port operators and port authorities have no historical links. SIPG seems to be following a strong expansion strategy focused around strategic investments along the Yangtze. The main aim is to bind cargo flows to the deepsea port facilities of SIPG in Shanghai. By developing and taking control over inland terminal facilities, SIPG has potentially taken up a very active role in the port regionalization process of Shanghai. SIPG goes beyond the catalyst role in an attempt to get a more direct impact on cargo flows. On the other hand, local governments in Chongqing and Wuhan have, in more recent years, forced SIPG to cede their controlling interest in the Chongqing Cuntan and Wuhan Yangsi Container terminals (see Cargonews Asia 16 March 2009).

The question rises, however, to what extent the strategies of dominant players SIPG and COSCO, which both have clear direct interests in the port of Shanghai, differ from the strategies followed by all outside owners. We define two factor variables: one indicating all outside owners (15 terminals), and one indicating only SIPG and COSCO ownership (seven terminals). Next we perform ANOVA tests on the means of the relevant operational, economic and geographic variables in our sample. All data is for the year 2006, but we have added throughput 2007 and growth rate 2006/2007 (resized for the number of terminals in 2006).

The ANOVA tests show that the grouping of ownership has some impact, although the focus on SIPG/COSCO ownership alone does not lead to any statistically significant differences in the means of the variables at the 5% level (Table 7). The factor that includes all outside ownership leads to significant differences for throughput 2006 and 2007, berthing capacity, distance and quay length. In each case, outside ownership is in the ports with larger quay length, larger berthing capacity, higher throughput and closer to Shanghai.

Table 6
Clustering results.

Variable group	% Smallest group	No. of clusters	1 − Wilk's Λ	η_p
Operational	7.1	4	0.988	
Quay length				0.840
Throughput				0.748
No. of cranes				0.807
No. of berths				0.638
Yard capacity				0.642
Economic	3.6	4	0.976	
GDP				0.851
Population				0.920
Geographic	17.9	3	0.981	
Distance				0.811
Berthing capacity				0.921
Combined	17.9	3	0.949	
Throughput				0.731
GDP				0.762
Berthing capacity				0.093

Table 7
ANOVA results for outside ownership.

	All owners		SIPG/COSCO	
	F	*p*	*F*	*p*
Number of cranes	1.367	0.253	0.986	0.330
Number of berths	0.109	0.744	0.740	0.397
Yard capacity	3.561	0.070	3.438	0.075
Quay length	8.215	0.008	1.009	0.324
Throughput 2006	7.420	0.011	1.815	0.190
Throughput 2007	6.567	0.017	1.738	0.199
Berthing capacity	4.747	0.039	0.575	0.455
Growth rate 2005/2006	0.136	0.716	1.114	0.301
Growth rate 2006/2007	0.019	0.891	0.641	0.430
Distance	5.226	0.031	0.309	0.583
GDP	0.063	0.803	0.186	0.670
Population	1.120	0.281	0.244	0.626

Note: *F* is the ANOVA *F*-statistic, and *p* is the *p*-value.

A test for homogeneity of variance in the full ownership grouping reveals that the variances are unequal, except for berthing capacity. For the case of the full ownership grouping, this is not a problem, because the two partial samples are almost equal in size (13 and 15). For the SIPG/COSCO ownership grouping, the test shows that variances are relatively equal (the Levene test of homogeneity of variances could not be rejected).

We also perform a multivariate variance analysis on the five variables (i.e. throughput 2006 and 2007, quay length, distance and berthing capacity) to find out how much the grouping variable determines the variance of the joint distribution of the four variables. The multivariate analysis of variance allows the identification, but also the examination, of the influence of covariates, which are variables that are related to the set of dependent variables. In Table 8 below, we report the following indicators: 1-Wilk's Lambda indicates how much the grouping variable determines the variance of the joint distribution, and partial eta squared (η_p) indicates the univariate effect on the dependent variables.

The results in Table 8 confirm the presence of weak evidence that a grouping of terminals by outside ownership can explain differences in the variance of a joint distribution made up of three variables (throughput 2006, quay length and distance). The investigation of an alternative model with additional covariates did not result in an acceptable alternative model.

We conclude that there is some impact of outside ownership on the size and location of terminals as measured by throughput, quay length and distance, but that this impact explains only about 33% of the variance of the joint distribution of these three variables. In

Table 8
Multivariate variance analysis.

	Cumulative distribution includes	1 − Wilk's Λ	η_p
Basic model		0.339*	
	Throughput 2006		0.222
	Throughput 2007		0.202
	Quay length		0.240
	Distance		0.167
	Berthing capacity		0.154
Alternative model		0.331	
	Throughput 2006		0.222
	Quay length		0.240
	Distance		0.167
Alternative model		0.144*	
	Throughput 2006		0.019
	Quay length		0.084
	Distance		0.060
	Throughput 2007 (covariate)	0.859	
	Berthing cap (covariate)	0.359	

* Not statistically significant at the 5% level.

addition, evidence for other relationships that might seem reasonable was not found: outside investors do not seem to look specifically at large communities (as measured by GDP and population), deep water locations (as measured by berthing capacity) or growth potential (as measured by growth rate).

7. Conclusion

This paper analyzed the economic structure of the Yangtze River container port systems, one of the most important inland container port system in the world. We have extended knowledge presented in earlier papers on the Yangtze River by performing a concentration analysis of terminal throughput, investigating groupings of terminals and studying the influence of outside ownership. Our findings shed some light on the development of the Yangtze River container port system, but also on the validity of the existing models for port system development in the context of the Yangtze River.

We find that throughput is relatively concentrated along the Yangtze River, and that this concentration has declined between 2002 and 2005. While deconcentration tendencies are described in standard models on port system development, the same models predict such dynamics take place in more mature stages of the development of a port system, when congestion and crowding out effects occur. Here, we observe deconcentration taking place in the very early stages of port development as well, when there are no strong load centres yet. This observation has a specific reason, that becomes apparent after some further testing.

Our further analysis provides evidence that spatial agglomeration of throughput along the Yangtze River is relatively low. This results from the combination of the nearest neighbour test and the spatial autocorrelation test. Furthermore, we find that three sets of variables, operational, economic and geographical, lead to three very different sets of port clusters. From the combination of the concentration tests, spatial agglomeration and cluster tests, we find that the geography of the river itself is the determining factor in the development of the river port system, and that the geographic structure is visible in the particular pattern and dynamics of the concentration of terminals in the Yangtze River container port system. This result has important repercussions for business. The bounded development of container terminals implies that there is an optimal efficient terminal size, and that it is unrealistic to strive for continuous growth, as is currently the case for many terminal operators along the Yangtze River.

Finally, we investigated the impact of outside ownership of ports. We find some evidence that high throughput, large quay length and distance close to Shanghai seem to be characteristics of ports with outside owners. This evidence is weak, however. Outside investors in Yangtze River container ports do not seem to base their investments specifically on decision variables such as large communities (as measured by GDP and population), deep water locations (as measured by berthing capacity) or growth potential (as measured by growth rate).

Given that the development of container terminals along the river may be limited by the geographical conditions, there is a considerable incentive to start new terminals. The entry of new container terminals on the Yangtze River can potentially prevent existing terminals from reaching a minimum efficient scale in their operations (see Kaselimi et al. (2010) on minimum efficient scale (MES) in a port terminal context). As this issue has not been addressed in this paper, it constitutes a prime object for future research and a key issue in the sustainable development of the Yangtze River container terminal market.

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