Container Barge Network Development in Inland Rivers: A Comparison between the Yangtze River and the Rhine River

Abstract:

The formation of barge networks on rivers and associated inland port systems is subject to a complex set of influencing factors and mechanisms. This paper aims to present a comprehensive comparative empirical analysis focusing on the container shipping (barge) network in the Yangtze and the Rhine. This analysis is supported by extensive datasets on both river basins, incorporates the latest development on both rivers and is grounded on concepts and methods coming from transport geography and economic geography. We find that a large diversity might exist in how inland port systems and related gateway seaports are dealing with cargo flows and supply chains. In view of explaining this diversity, we make a distinction between geographical/nautical aspects, macro-economic factors and institutional/governance factors. In particular, we discuss the role of institutional and governance factors in barge network development by using the concepts of selection, retention and variation.

Keywords: Inland Waterway Transport, Container Barge Network, Comparative Study, Cargo Concentration, Yangtze River, Rhine River

1. Introduction

The Yangtze River and the Rhine River are the two most important inland rivers in the world in terms of freight transport and play an increasingly important role in regional economic development. The two rivers have witnessed time-specific processes of containerization and associated barge shipping configuration linked to the macro-economic and logistics development stage of the regions concerned, i.e. China and northwest Europe respectively. Although existing studies have addressed the barge network configuration of these two rivers, few attempts have been made to compare their respective development stages. This paper provides a comprehensive comparative analysis on the two rivers in order to understand if there exists a general evolutionary pattern of inland river container barge network development.

As the mother river of China, the Yangtze River and its branches cover more than half of provinces as well as population in China and play a critical role for domestic transportation of China. The freight volume of Yangtze River is over 2 billion tons annually (Yangtze River Shipping Administration, 2018). The Rhine basin covers 5.4% of the land area of the EU 27 countries, and this area houses nearly 15% of the total population of the EU 27 and generates an elevated 18.7% of the gross domestic product of the EU27 (Notteboom, 2017). The Yangtze River (Figure 1) and the Rhine River (Figure 2) have their unique geographic conditions. Both rivers can be divided in a lower, middle and upper reach. Each reach includes a range of inland container ports and terminals of different scales.

In the past 40 years, both the Rhine River and the Yangtze River have witnessed a strong growth of container traffic and dynamics in the barge network configuration. This rapid increase and development of container traffic has changed the spatial and functional configuration of the respective container shipping networks in these river basins. The container shipping network in turn reshaped shipping practices and supported regional economic development.

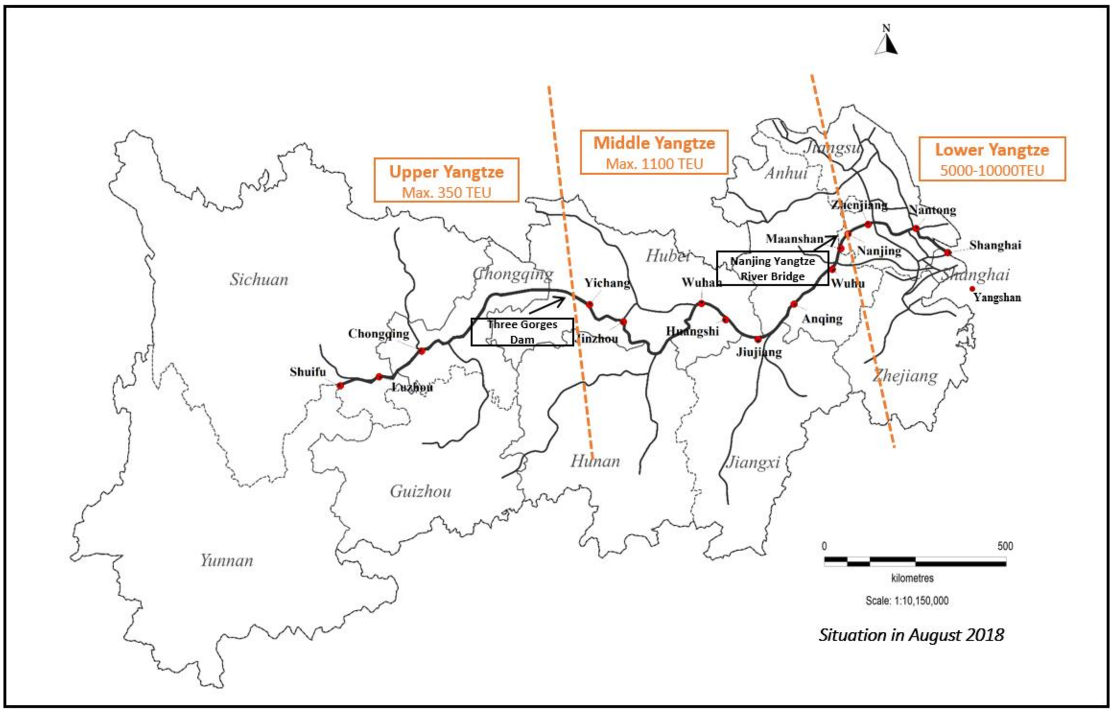
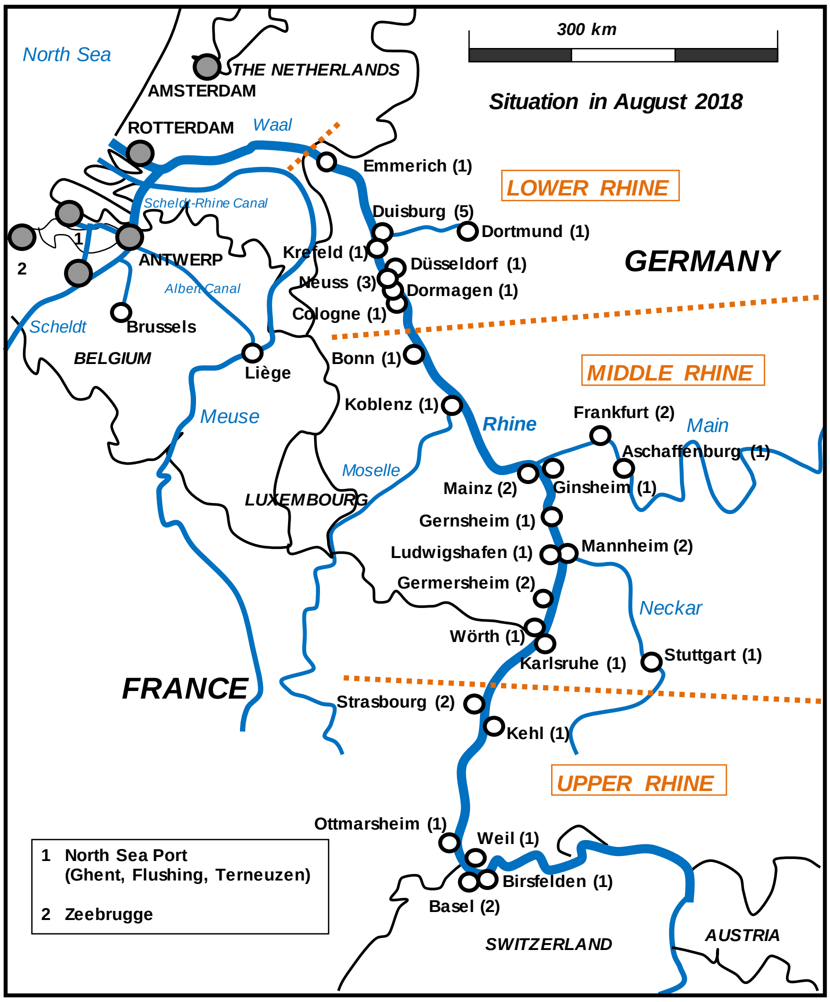


Figure 1. The different reaches of the Yangtze River



Note: Duisburg (5) implies there are five barge container terminals in Duisburg

Figure 2. The different reaches of the Rhine River

The container barge network development on the Rhine River has been investigated by many researchers. The early works include Notteboom (2001) and Notteboom and Konings (2004). These studies explore the organisational changes in the European container barge industry and its impact on the spatial dynamics in the European container barge network. They distinguish four separate phases in barge network development, focusing on growth, concentration and dispersion of inland container terminals in the network in connection to port system development. The potential role and spatial configuration of a container barge network is also strongly entwined with the availability and navigability of the inland waterways and canals, the cargo dispersion patterns along the waterway system and the distances between the gateway ports and the economic centers in the hinterland. Also, Frémont et al. (2009) present a four-phased model on barge network development. By focusing on the Seine basin (linked to gateway port Le Havre) and the Rhône River (in combination with seaport Marseille) in France, their model explicitly considers the interdependence between the setting up of combined waterway-road services, and the competition between ports and the competition between shipping lines. They argue that infrastructure, characteristics of the market, services and terminals, end-haul road transportation and market organization are the key factors affecting the development of container transport by barge. More recently, Notteboom (2017) conceptualized the interdependency between port systems and barge networks and presented a life-cycle approach to barge network development, using the barge connectivity between the Benelux seaport system and the Rhine basin as a case study. The study underlines that barge networks have to meet the cargo demand and requirements of global supply chains, but are also affected by operational considerations of barge operators in terms of service network configuration and barge scale and utilization levels.

Academic works on the Yangtze River are of more recent date. In a study on seaport system development in China in the period 1990-2005, Rimmer and Comtois (2009) point to the penetration of containerization inland along the Yangtze River, strongly facilitated by state-owned COSCON, as one of the main growth factors for the port of Shanghai. The spatial dynamics of container barge network in Yangtze has also been widely examined. Veenstra and Notteboom (2011) presents a containerized cargo concentration analysis for the inland ports on the Yangtze River for the period 2002-2010 and link it to the port regionalization concept introduced by Notteboom and Rodrigue (2005). They argued that the Yangtze River container transportation system is going through a regionalization phase. This process started on the lower Yangtze River but is now also moving upstream. Based on the previous findings, Wang and Ducruet (2012) examine the impact of the Yangshan port on the spatial pattern of the Yangtze River Delta since the 1970s, and they identify the noticeable development deviations between Yangtze River and the general port system spatial evolutionary models. With strong national policy support, Shanghai-Yangshan has taken the form and function of a dual hub and gateway for ports along Yangtze River. Zheng and Yang (2016) discuss the possible hub-and-spoke container barge network on the Yangtze River to exploit the economies of scale within the existing Yangtze River transport network. Their findings support the trends toward cargo concentration and port regionalization along the Yangtze River. Some recent papers explore the influencing factors shaping the port system. Li et al. (2014) argue that the development of the Yangtze River shipping network is strongly influenced by institutional changes at different levels of government in line with the path dependent transformation of the Chinese central planning economy. Yang et al. (2017) suggest that geographical conditions, institutional factors and national policy, industrial agglomeration, and changes in market supply and demand along with technology updates drive the reshaping of the shipping network in the Yangtze River.

We only find one study providing a comparative analysis of the Yangtze and Rhine rivers. Notteboom (2007) presents a qualitative assessment of similarities and dissimilarities between the spatial and the functional development of the container river service networks of the Yangtze River and the Rhine River. While such developments are location-specific and time-specific, the study reveals the Yangtze service network has the tendency to converge, in more than one aspect, with the (historical) development pattern of inland container services in the Rhine basin.

A few conclusions can be drawn when examining extant literature on barge network and inland port development.

First, extant literature basically analyzes two aspects. The first aspect relates to the development of (inland) port systems in terms of configuration transformation, e.g. by measuring cargo concentration or deconcentration patterns. The second aspect explores the factors which can explain the transformation of a river’s network configuration. In a number of studies both aspects are combined to present models on the spatial and functional development of container barge networks on rivers (e.g. Notteboom and

Konings, 2004; Frémont et al., 2009; Veenstra and Notteboom, 2011; Wiegmans et al., 2015; Notteboom, 2017; Yang et al., 2017), which are largely inspired by similar models found in seaport system development literature.

Second, the existing spatial models on inland port system development portray a high degree of path dependency in the development of inland ports at a regional scale. Path dependence explains how the set of decisions one faces for any given circumstance is limited by the decisions one has made in the past. Future events are not independent from past events and the sequence of events makes a difference for the outcome. The focus on path dependency seems to suggest that inland port systems as well as the container barge shipping network would follow a similar evolutionary development path. It can be argued, however, that development processes also show a certain degree of contingency. Strategies and actions of market players and other stakeholders may deviate from existing development paths. This might lead to path disruption, a concept that has only received some attention in the context of the more institutional aspects of container barge network development (see e.g. Li et al., 2014).

Third, the empirical research found in existing literature focuses on single river systems in a specific part of the world, e.g. the Rhine, the Yangtze, the Seine, etc. Except for the qualitative work of Notteboom (2007), there are no comparative studies analysing development patterns in inland port systems in different parts of the world. While existing studies rightly argue that the development path of a barge network is location-specific and time-specific and subject to a specific economic system with a different mix of economic actors and the government, it is not clear how differences in such a mix across regions might lead to some level of disparity among inland port systems. For example, some inland port systems might be subject to a careful (central) planning by policy makers and investors, while others might be more the result of ad hoc decisions and investments fuelled by "windows of opportunity" that arise (see Jacobs and Notteboom, 2011).

This paper is the first study to present a comprehensive comparative empirical analysis focusing on the container shipping (barge) network in the Yangtze and the Rhine. This analysis is supported by extensive datasets on both river basins, incorporates the latest development on both rivers and is grounded on concepts and methods coming from transport geography and economic geography. The novelty of this study lies in the combination of descriptive and explanatory methods to analyse and compare the dynamics in the barge networks in both river basins. By following this approach, this paper can help readers to comprehensively and thoroughly understand the general evolution model of container shipping (barge) networks in inland river systems.

2. Research design and methodology

We present and apply a two-step methodological approach to analyse and compare container barge network development on the Yangtze and Rhine Rivers (Figure 3). First, we conduct a descriptive analysis to compare the overall evolutionary patterns of the two rivers. Following this, we further provide an explanatory analysis to figure out the factors which affect the evolutionary patterns of two rivers. The descriptive analysis thus helps to uncover the differences in their evolutionary patterns and the explanatory analysis explains these differences.

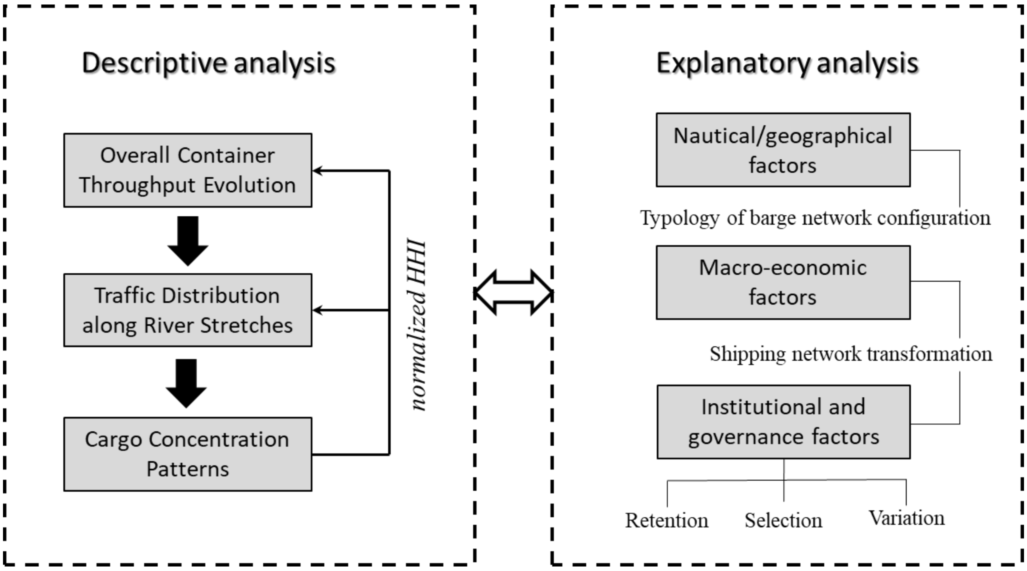


Figure 3. Research design

2.1 Descriptive analysis

We present a **descriptive analysis** of barge network development on the two rivers. These networks consist of nodes (the inland ports) located laterally along the respective rivers. We analyse spatial cargo distribution in these networks by analysing and comparing the overall evolution of the container throughput in both rivers and its respective reaches, and cargo concentration and deconcentration patterns in the inland port systems of both rivers. The term 'cargo' thus refers to container throughput in this study. A detailed analysis of scheduled container liner services on the rivers falls beyond the scope of the descriptive analysis, although liner services are also a feature of container barge networks.

The measurement of cargo concentration/deconcentration is a common theme in seaport geography literature (Ng et al., 2014). Ducruet et al. (2009) identified 34 academic studies on port system concentration published between 1963 and 2008. A more recent study is Wilmsmeier et al. (2014) on port system evolution in Latin America and the Caribbean. The most used measures in extant literature include C4 index (i.e. the combined market share of the four largest ports in the system), the Hirschmann-Herfindahl index (HHI), Lorenz curves and the Gini coefficient and the associated Gini decomposition analysis (Notteboom, 2006).

While the analysis of cargo concentration patterns is a mature research area in (sea) port geography literature, there are hardly any studies applying concentration measures to inland port systems. A notable exception is the study by Veenstra and Notteboom (2011) which examines cargo concentration levels on the Yangtze River in the period 2002-2010 using a combination of Gini coefficients and Teil indices (Theil-T and Theil-L redundancies). However, as the dataset only relates to the short time frame of 2002-2010, the study could only detect medium term concentration dynamics in the Yangtze River.

The virtual absence of studies on cargo concentration in inland port systems is partly due to data availability issues. Container throughput data for seaports are widely available as they are made public by seaport authorities, (national) statistical offices and international or regional port associations (such as International Association of Ports and Harbors and European Sea Ports Organisation). While a number of inland ports and public agencies publish cargo throughput data online, there is a general lack of publicly available inland port data, both in Europe and China. In Europe, the existing gap between seaports and inland ports in terms of data collection and publication cultures was confirmed during the European Commission's Portopia project (Portopia, 2016).

In this study, we apply the HHI index to measure cargo concentration patterns along the two rivers, since the HHI index can reflect changes in barge networks including amongst smaller ports. The HHI index is a commonly accepted measure of market concentration, by means of comparing the share of an individual company in relation to the industry. In this study, it is calculated as:

$$H_j = \frac{\sum_{i=1}^{i=n} TEU_{ij}^2}{(\sum_{i=1}^{i=n} TEU_{ij})^2} \quad , \frac{1}{n} < H_j < 1 \qquad (1)$$

where H_j is the HHI index of inland port system *j*, *n* is the number of inland ports, and TEU_{ij} is the TEU throughput of inland port *i* in inland port system *j*. The value of the HHI index ranges from 1/n to 1. Since the number of inland ports may differ between inland port systems, the Normalized HHI is used when the concentration levels of two inland port systems are compared:

$$H_j^N = \frac{HHI_j - \frac{1}{n}}{1 - \frac{1}{n}} \qquad (2)$$

A high HHI value denotes a high level of concentration and vice versa (Rhoades, 1993).

2.2 Explanatory analysis

2.2.1 Factors driving the inland river barge network

We present the **explanatory analysis** of barge network development on the two rivers by examining the factors that might explain the observed throughput development and the similarities and differences between the barge network development paths of the Yangtze River and Rhine River. Seaport geography literature has commented on the drivers of cargo concentration and deconcentration paths in port systems. Wiradanti et al. (2018) updated the work of Ducruet et al. (2009) on the concentration and deconcentration factors in seaport system development and show how these factors emerged in the time periods 1970-1990, 1990-2008 and post-2008. These factors relate to port city dynamics, congestion/lack of space, (dis)economies of scale, dynamics in foreland and inland connectivity, technological developments, changes in investments patterns and government policy (e.g. export-led policies and regional development plans). Research on factors affecting the development path of inland port systems is sparse. Based on extant literature (see section 1), we cluster the factors affecting barge network development paths in three categories (see also Figure 3):

- *geographical/nautical factors*: these relate to the nautical accessibility of a river basin or river stretches, the geographical setting of the service areas of inland ports and the spatial interdependencies between the inland port system and the associated seaports;

- *macro-economic factors*: these refer to the functional and spatial organisation of the economic system in and around the river basin, the growth of cargo-generating activities and the containerisation process of trade flows between the river basin's service area and other economies in the region and around the world;
- *institutional and governance factors:* Institutions consist of a set of formal or informal rules (North, 1990; Strambach, 2010). A distinction can be made between the institutional environment (i.e. legally enforced rules and regulations, but also informal conventions, customs, routines and norms) and institutional arrangements referring to organizational forms (firms, state bureaucracies, governance systems, etc.). Inland port systems are subject to institutions and governance settings in which a variety of actors and interests from various territorial scales interact, conflict and form coalitions.

2.2.2 Selection, Retention and Variation

There is an extensive literature on 'institutions' and 'governance' in a seaport setting (see e.g. the edited works of Brooks and Cullinane, 2006 and Brooks et al, 2017). The seaport-related literature suggests that institutions enable, constrain and refract industries and economic development in spatially differentiated ways. The notion of path dependence has been used to explain the unique development trajectories of ports and the diversity of governance structures.

Because of the place specific nature of rivers and inland ports, institutional differences in the way inland ports are owned, managed and developed persist. Still, the role of institutions and governance in barge transport and inland port development has received only limited attention. Notable exceptions include the works of Li et al. (2014) and Li et al. (2017) analysing the impact of changes in institutional and governance practices at different levels of government in China on the development of inland waterway transport in the Yangtze River and the Pearl River respectively.

To factor in institutions and governance as explanatory factors for inland port system development in the Rhine and Yangtze basins, we use concepts and insights from economic geography literature. We argue that the outcome of inland port system development is dependent on a mix of path dependency and contingency. We conceptualize those mechanisms that lead to path dependency and those that lead to path disruption or even path destruction by identifying three basic principles driving evolutionary inland port systems: selection, retention and variation (see also Nelson and Winter, 2002 and Glückler, 2007 for the terminology used).

Selection relates to the competitive process that selects winners and losers in inland port systems and to the formation of competitive and or cooperative linkages between the actors in an inland port system. The outcome of selection processes is not only depending on the external selective environment (exogenous), but also on the strategic intentions and actions of the actors involved (endogenous). Exogenous developments affecting ports are well documented in literature: macro-economic developments, globalization and trade patterns, supply chain dynamics and logistics integration and transport deregulation to name but a few. Endogenous factors can relate to e.g. inland terminal awarding procedures and decisions, internal market competition or the strategies of inland port players. Selection processes can occur among incumbent actors in the inland port system (e.g. established inland terminal operators) but also in relation to new entrants with no previous links to the inland port system (e.g. a deep-sea terminal operator acquiring an inland terminal facility).

Retention refers to the structural mechanisms that cause new developments to reinforce the existing hierarchy in an inland port system. Past choices have a structural effect on the natural inclination for new tie selection to reproduce and reinforce an existing system. Path dependency in the development of an inland port system might be increased by some behavioural mechanisms influencing the interaction among actors in the inland port system. One of these mechanisms is preferential attachment. The actors in a specific inland port system with many ties are more likely to receive new ties in the future. For example, an inland terminal operator with a strong track record has a good position to establish new customer relationships or relationships with other actors in the market. Embedding is another mechanism strengthening path dependency. The mechanism of embedding assumes that future ties form around existing strong ties by processes of trust. Preferential attachment and embedding can lead to self-reinforcing effects whereby established inland ports become even more dominant in an inland port system.

The concept of **variation** relates to both exogenous and endogenous mechanisms that enable novelty and path disruption in the development of an inland port system. Variation is strongly linked with contingency as it countervails against existing trajectories and against the retention mechanisms outlined above. It is strongly influenced by 'windows of opportunity' and 'critical junctures' (Jacobs and Notteboom, 2011) and action-reaction patterns in strategic behavior of public and private agents. Variation can lead almost overnight to a new hierarchy in an inland port system or to a new competitive setting among inland terminal facilities.

In the following sections 3 and 4, we identify similarities and differences between the development patterns of the two rivers, and we summarize the general development pattern with evidences led by three influencing factors.

3. Descriptive analysis of inland port system development on Rhine and Yangtze

In this section, we review the evolution of the total container throughput along the Rhine and Yangtze Rivers, the changes in cargo traffic distribution along the river stretches and also the changes in the cargo concentration levels. By doing so, we aim to identify the similarities and differences in the rivers' development trajectories, and to examine if a general development pattern exists.

3.1 Container throughput evolution

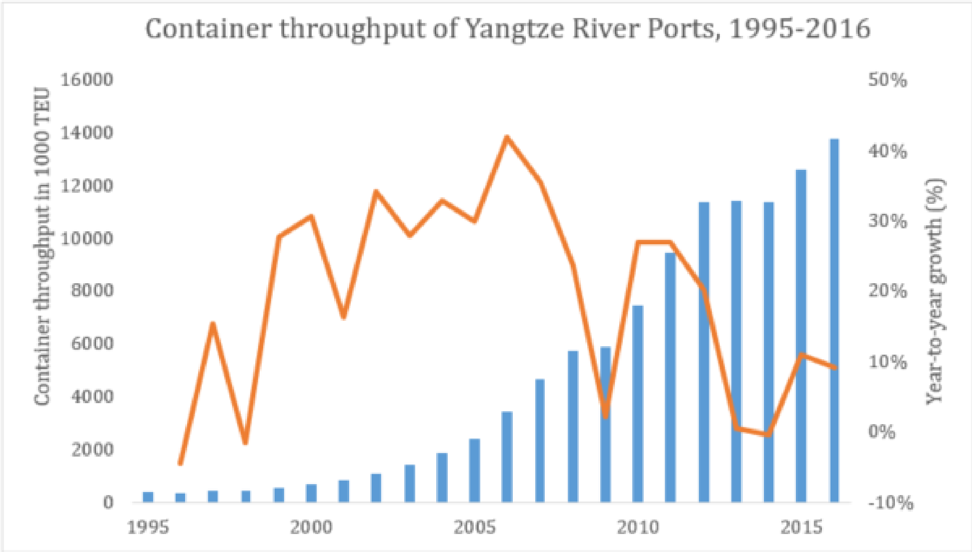
To achieve our research objective, total container throughput data per inland port along the Yangtze and Rhine were collected. The Rhine container traffic dataset covers 26 inland ports for the period 1970-2016. The throughput dataset for the Yangtze River includes 1995-2016 figures for 22 ports. The collection of historical data proved to be particularly difficult, so additional data had to be obtained through an extensive search of media archives (specialized transport and logistics newspapers and magazines) and personal contacts with actors involved in inland ports.

A wide range of data sources was used to compile throughput statistics (table 1):

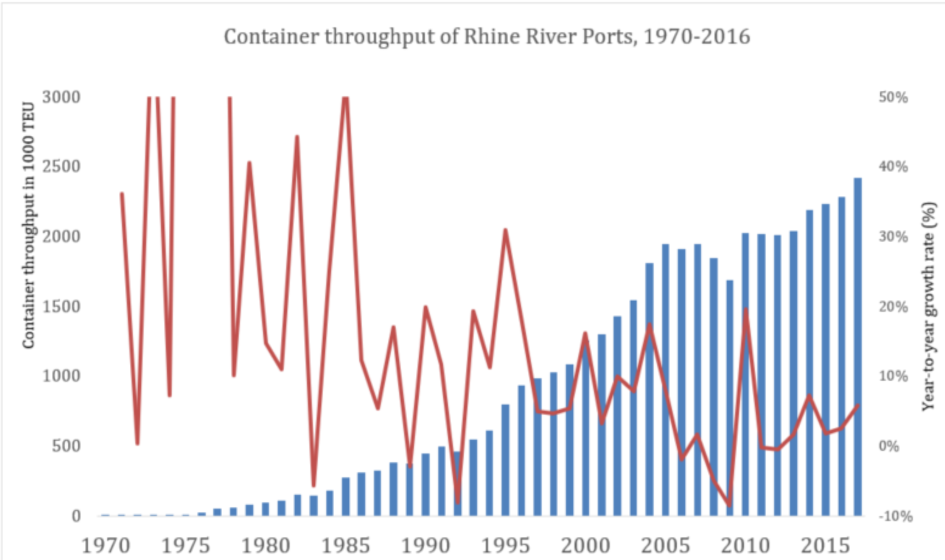
Table 1 Data sources for this study

Data Sources	**Rhine River**	**Yangtze River**
National statistical offices	Destatis (2018) for Germany	National Bureau of Statistics of China (2018); Ministry of Transport of China (2018).
Regional statistical offices	Information und Technik Nordrhein-Westfalen (2017) for the German state of Nordrhein-Westfalen	Nil
Individual public or private inland port authorities and inland terminal operating companies	Duisport (Duisburg), Swissterminal and Rhine Europe Terminals	Shanghai International Port Group (SIPG)
Inland port associations and co-operation schemes	European Federation of Inland Ports (EFIP) and Upper Rhine Ports	Nil
Statistics and reports published by organizations	Central Commission of the Navigation on the Rhine (see e.g. CCNR, 2018), European Barge Union (EBU), Inland Navigation Europe (INE), Verein für europäische Binnenschiffahrt und Wasserstraßen (VBW)	Fifty Year Statistics Compilation of New China Traffic (1949-1999), Compilation of National Transport Statistics of China (2001-2018)

Figure 4 shows the total container throughput evolution and year-to-year growth figures for the Yangtze River (part a) and the Rhine River (part b). Although strong fluctuations in year-to-year growth figures exist, both rivers experienced a steep growth in the early stages of their development followed by a much weaker growth pattern.



(a) Yangtze River



(b) Rhine River

Figure 4. Total container throughput and growth of Yangtze River and Rhine River

As for the Yangtze River, since at the turn of the century when port decentralization started and China joined WTO, the average growth rate has increased significantly with an average annual growth rate of approximately 30% which reached a peak of more than 40% in 2006. In 2009, the shipping industry was heavily affected by the global financial crisis and the growth rate fell to only 2.1%. But it rebounded to over 20% from 2010 to 2012, which was mainly due to the four-trillion-RMB investment from the Chinese central government in response to the financial crisis. Then it fell to close to 0% in 2013 again when the economy of China turned from high-speed development to medium-speed and stable development. The GDP growth rate of China dropped from more than 10% to less than 8% since 2013 (IMF). Since 2015, the container throughput in the Yangtze basin resumed growth, although the growth rate never reached 10%.

The Rhine River achieved its fastest growth during the 1970s and 1980s. In the late 1970s early 1980s, barge operators started to offer scheduled liner container services on the Rhine. For this purpose, operators divided the Rhine into three navigation stretches, namely the Lower Rhine (as far as Cologne/Bonn – only limited number of services at that time), the Middle Rhine (from Bonn up to Karlsruhe) and the Upper Rhine (from Karlsruhe up to Basel in Switzerland). This operational division of the Rhine in three navigation areas is still used today. Once punctuality could be guaranteed by fixed departure schedules for each navigation area, with exceptions only occurring in case of low water levels, barge transport quickly gained in competitiveness. No less than twenty new Rhine terminals (mostly on the upper and middle sections) were opened in the period 1980-1987, mainly by barge operating companies who saw the operation of their own single-user terminals as a way to guarantee success of their liner services. The introduction of many new scheduled container services between gateway ports Rotterdam and Antwerp and the Rhine basin led to a growth of Rhine traffic from 20,000 TEU (1976) to about 311,000 TEU ten years later. In the mid-1980s, barge carriers started to operate joint liner services on the different navigation areas of the Rhine in order to raise the service level and prevent destructive competition (e.g. the Fahrgemeinschaft Oberrhein or Upper Rhine transport collective, Konings, 1999). In 1998, the container volume reached over 1 million TEU for the first time. The number of terminals along the Rhine basin continued to increase in the new millennium. This was partly the result of new terminal operators arriving on the market (such as Rotterdam-based deepsea terminal operator ECT in Duisburg in 1999) and the emergence of entirely new terminal areas along the Rhine and its tributaries, e.g. Aschaffenburg, Krefeld and Mannheim. The growing volume base led, where possible, to scale increases in vessel size. For example, larger barges were being introduced on the lower reach such as the Jowi ship class with a slot capacity of up to 500 TEU and push convoy combinations of up to 600 TEU. In the period 2005-2008, total container throughput stabilized at 1.8-1.9 million TEU. Crisis year 2009 brought a volume drop of approximately 9% followed by a strong recovery in 2010. After a stagnation of the throughput between 2010 and 2013, growth resumed in recent years to reach a record throughput of 2.28 million TEU in 2016.

3.2 Traffic distribution along the river stretches

The direction of spatial development over time differs between the Yangtze River and the Rhine River. This is illustrated by Figure 5 which shows the total container throughput of the different reaches in the Yangtze and the Rhine.

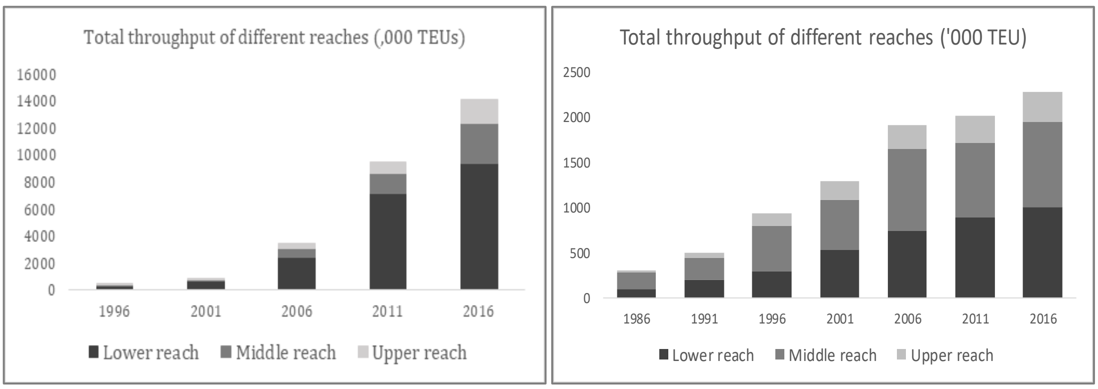


Figure 5. Total container throughput of different reaches in the Yangtze (left) and the Rhine (right)

The Yangtze River witnessed a development pattern initiated downstream and moving upstream. In the Yangtze River, containerization first occurred at the lower reach in the early 1990s. The manufacturing activities started along the lower reach as this was the first region to be opened to foreign trade and is easy to be accessed by ships. The lower reach of the Yangtze River has always accounted for the majority of the Yangtze river container traffic over the investigated period, although its share decreased from 91% in 1996 to 72% in 2006, and finally to 67% in 2016. The quick growth of the middle and upper reaches is attributed to the implementation of the western and central development strategy in China since 2000 (the so called 'Go West' and 'Rise of Central' strategies) and the transfer of manufacturing activities from East China to West China in recent years.

In contrast, the containerization process along the Rhine River found its origins in the middle Rhine section in the early 1970s with the lower Rhine and upper Rhine reaches only playing a very modest role throughout the 1970s and early 1980s. At the time, barge operators took the view that barge container transport on the Rhine could only effectively compete with road transport over distances of at least 500 km (distance between gateway port and inland port), given the comparatively high fixed costs and low variable costs of barges. This was not the case for the Yangtze River, because the surface transport infrastructure in China was poor in the early stage. In the second half of the 1980s, the lower Rhine area generated more and more containerised trade flows which enabled the deployment of larger vessels and higher service frequencies. This created more favourable market conditions for barge transport also on shorter distances from the gateway ports. It also brought a surge in large-scale terminal initiatives and scheduled barge services to the lower Rhine from 1985 onwards. In 1986, the middle reach of the Rhine still handled 59% of the total Rhine container traffic compared to 31.5% for the lower Rhine. By 2001, the container throughput levels on both river sections were of the same magnitude. In 2016, the lower Rhine handled 44% of the total Rhine throughput, compared to 41.4% for the middle reach. The upper Rhine section has always been the smallest in volume terms, with its containerised cargo share fluctuating between 10 and 16% of total Rhine volume.

The development difference among stretches between the two rivers can also be explained by the inequality of economic development. The developed region (e.g. lower reach of the Yangtze) generally has a higher maritime transport demand and well-developed port facility as they adopted containerisation early.

3.3 Cargo concentration patterns on Yangtze and Rhine

Figure 6 shows the normalized Herfindahl–Hirschman Index (HHI) of total container throughput for the Yangtze and the Rhine. It can be observed from Figure 6 that both rivers have experienced a strong cargo deconcentration trend in their early development stages followed by a somewhat diverging development path. The Rhine river reached its lowest concentration level in 1995 after two decades of continuous cargo deconcentration. Since then, the Rhine is witnessing a modest but continued increase in its cargo concentration level to reach a normalized HHI of around 0.06 in 2016. The Yangtze underwent a strong cargo deconcentration phase between 1995 and 2005, followed by an equally strong concentration trend between 2005 and 2012. In the past few years, the normalized HHI fell back to a level of 0.11-0.12, which is higher than the value of 0.05-0.06 for the Rhine.

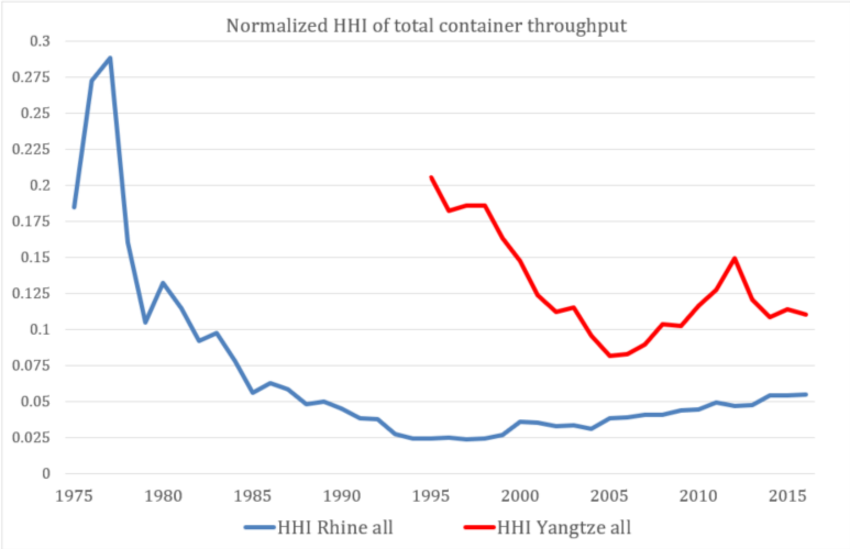


Figure 6. Comparison of the normalized HHI between Yangtze and Rhine

When comparing Figures 4 and 6, we find the two rivers show a similar development in the deconcentration stage (i.e. the period 1975-1995 for the Rhine and 1995-2005 for the Yangtze): high annual growth figures are combined with a decrease in cargo concentration levels. This is because, in both rivers, more inland ports were developed during the respective periods and the whole port system expanded in spatial terms over different reaches. Afterwards, the development paths of the two rivers clearly diverged. Since 1995, the Rhine River combines a modest concentration trend with, on average, a decreasing tendency in annual growth rates. In the Yangtze, both growth rates and the normalized HHI values have fluctuated strongly since 2005.

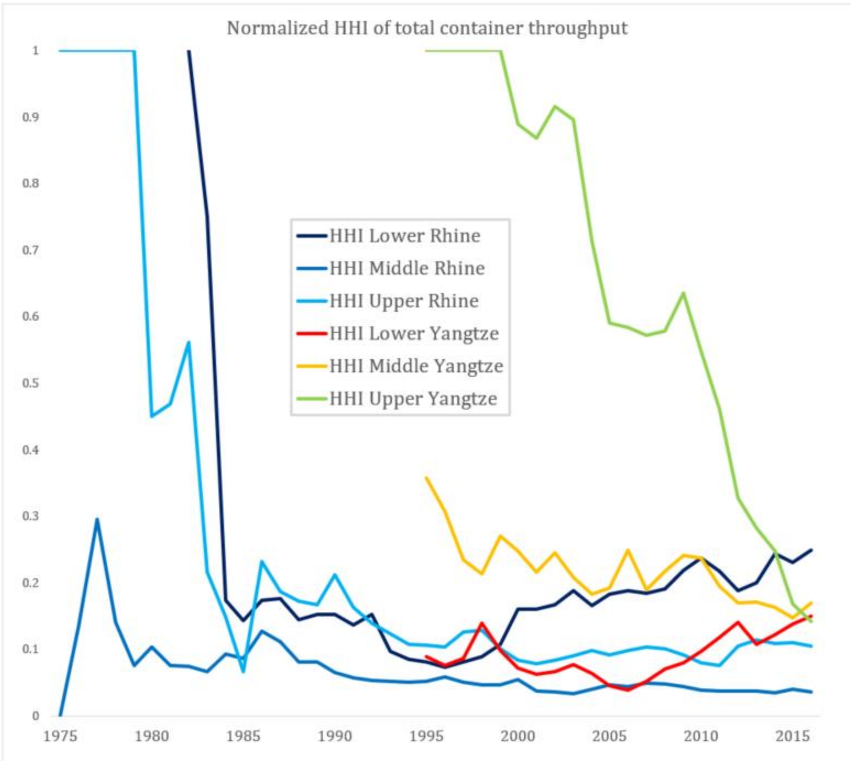


Figure 7. Normalized HHI for navigation areas of the Rhine and Yangtze

To provide a more detailed insight on the underlying dynamics, Figure 7 presents the values for the normalized HHI for the six navigation areas under consideration. The Yangtze River is much longer than the Rhine River and its reaches are at different economic development levels. The lower Yangtze is undergoing a concentration process since 2006, while the middle and upper reaches are confronted with a deconcentration process. Between 2005 and 2012, the former process dominated the latter, thus in those years the normalized HHI index of the whole Yangtze River was on the rise. However, from 2012 to 2016 the ports in the upper and middle reaches became more influencing in term of total container throughput, which reversed the concentration trend.

It is interesting to observe that the concentration levels in all three reaches of the Yangtze gradually converged to more or less the same level in 2016. This is not the case in the Rhine where the gaps between the HHI indices of the three reaches are gradually widening. The lower Rhine is clearly showing a cargo concentration trend since the mid-1990s. The HHI for the middle reach is the lowest of the three navigation areas and has a very modest tendency to decrease even further. While the upper Rhine has observed some fluctuations, the overall trend since the early 2000s points towards a stabilization of the concentration level. The clear concentration trend in the lower Rhine dominates the concentration patterns in the other navigation areas, thus contributing to the modest but continued concentration trend in the Rhine since 1995.

4. Explanatory analysis of inland port network development on Rhine and Yangtze

From the above analysis, multiple influencing factors might explain the observed container throughput evolution and concentration patterns in the river basins, as shown in Table 2.

Table 2. Summary of influencing factors on inland river development patterns

Descriptive analysis	**General development pattern**	**Influence factors**
Container throughput	A steep growth followed by a decrease, but with fluctuation	Macro economic factors (economic development, global crisis, etc.); Institutional and governance factor (national investment, market entry of port operators, etc.)
Traffic distribution	From downstream to upstream (Yangtze River); From middle stream to two ends, particularly downstream (Rhine)	Geographical and nautical characteristics; Institutional and governance factors (opening up of market initiated from downstream of Yangtze; China western and central development strategy, competition from road transportation, employment of large vessel, etc.)
Cargo concentration patterns	Deconcentration trend in early development stages followed by a diverging development path	Geographic characteristics (reaches are at different economic development levels, transshipment, etc.); Institutional and governance factor (port system expansion in spatial terms, port integration, etc.)

Following the previous section, in this section, we investigate these influencing factors and how they exerted their influence on shaping the barge shipping networks in the two rivers. As indicated in section 2, we make a distinction between geographical/nautical aspects, macro-economic factors and institutional/governance factors.

4.1 Geographical and nautical characteristics

The nautical conditions of the river and the geographical features of seaports and inland ports play a critical role in shaping the container shipping network along both the Yangtze and the Rhine. Unlike rail networks, rivers typically have a treelike structure with limited or no lateral connections between the different branches or tributary rivers. Vessel capacity that can be deployed is restricted and not homogeneous due to varying draft limitations and other physical conditions in various parts of the river basin.

The development of the shipping network in the Yangtze River has been heavily shaped by its geographic characteristics. The Yangtze basically can be divided into three reaches in terms of water depth. Ships as large as 10,000 TEU can only call the ports at the mouth of Yangtze River, such as Taicang and Zhangjianggang. Container ships with a capacity of 5,000 TEU can sail at farthest to Nanjing, thus from Taicang to Nanjing is recognized as the lower reach of Yangtze River. The Nanjing Yangtze River Bridge and Three Gorges Dam lock are generally regarded as the dividing lines for the different stretches of the Yangtze River. Only ships with a capacity of less than 1,100 TEU can sail to the middle reach which starts from Nanjing (due to the height limitation of the Nanjing Yangtze River Bridge) and ends in Yichang, close to the Three Gorges Dam. Only container barges of less than 350 TEU can pass the Three Gorges Dam lock system to sail to the upper reach of Yangtze River. The ships sailing along Yangtze River are mostly barges, which are not allowed to sail in the sea and coastal waters. Thus, the container transport from ports at the middle and upper reaches to any seaport outside the river basin (for example the island container terminal complex of Yangshan) typically requires a barge-deepsea transshipment operation at one of the ports of the lower reach or the mouth of the Yangtze.

The reaches are divided by two big chokepoints in the Yangtze River, i.e. the Nanjing Yangtze River Bridge divides the lower Yangtze River from the middle and upper River and the three Gorges Dam only allows very small ships to reach ports in the upper reach of the river. Since big ships are restricted by the two chokepoints, the ports located before the chokepoints, such as, Wuhan (note that Yichang is the closest port to the three Gorges Dam, however Hubei province has invested more resources in developing Wuhan because it is the capital city of Hubei) and Nanjing (also the capital city of Jiangsu Province) have taken great advantage of their locations. Container transshipment operations via these ports bring cost savings to the carriers as they can stretch the voyages of the larger ships. Recently, the ports located at the mouth of Yangtze River, such as Taicang and Nantong also achieved a very quick increase of container throughput, because deep-sea container vessels are not allowed to go deeper into the Yangtze river. In 2012, the Ministry of Transportation and the National Development and Reform Commission has categorized Taicang as a seaport and cancelled the compulsory pilotage for the ships that would call Taicang port after 2013. The container throughput of Taicang increased by almost 25% from 244,000 TEU in 2013 to 439,000 TEU in 2016.

Given the existence of two chokepoints, a double transshipment pattern has been formed in the Yangtze River. The ports close to chokepoints such as Wuhan at the middle reach, Nanjing at the lower reach and Taicang at the mouth of the Yangtze River, gradually attract more container cargo and become the river hub ports, which also drives up the concentration level of the Yangtze River after 2005.

Figure 8 shows the current typology of container barge network configurations on the Yangtze River.

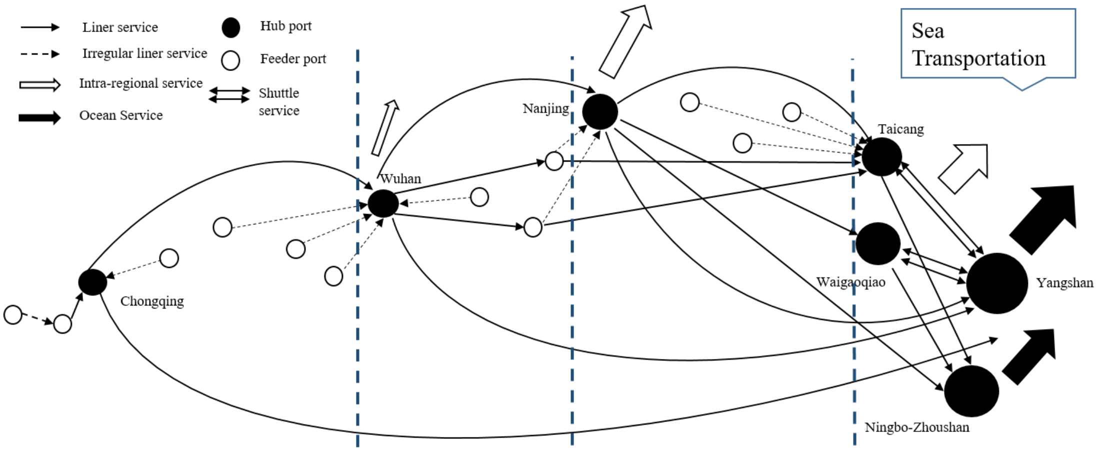


Figure 8. Current typology of container barge network configuration of the Yangtze River

A similar situation also exists in the stretches of the Rhine River which features different nautical conditions imposing limitations to ship size.

The lower Rhine (Emmerich to Cologne/Bonn) has the best draft and river width profile allowing motor barges of up to 500 TEU and push convoys of up to 600 TEU to reach the ports along this reach. While all ports in principle share these nautical conditions, the port of Duisburg, the largest inland port of Europe in volume terms, has been the most successful in leveraging on these conditions. Duisburg is the most important port of call for large barges coming from Antwerp and Rotterdam. The inland port is currently home to five barge container terminals, extensive logistics and warehousing facilities and has developed itself into a key hub for intra-European and Asia-Europe railway services. The ports on the middle Rhine (from Bonn up to Karlsruhe) have a slightly less favorable draft profile compared to the lower Rhine and the nautical conditions further diminish on the Upper Rhine (from Karlsruhe up to Basel in Switzerland).

In recent years, the middle and upper Rhine sections have increasingly been confronted with low water level conditions caused by draught. The summer of 2018 brought the lowest rainfall ever in the Rhine basin leading to record low levels at several points along the river. On the river stretches that were still navigable, the lower water level actually led to increased shipping traffic, as barges had to reduce the cargo load per sailing to reduce vessel draft and thus make more roundtrips to carry the same amount of freight. Low water levels increase barge freight rates and undermine service reliability, two major factors shaping competition with other transport modes. If low water level situations become even more frequent in the future, cargo owners and barge operators might revise the current barge network configuration in view of increasing supply chain reliability and resilience. Such a reconfiguration eventually could also affect the cargo concentration level on the Rhine and the respective throughput shares of the three river stretches.

4.2 Macro-economic factors

Shipping network transformation has a strong correlation with the macro-economic development of the regions and provinces along the river. We argue that these macro-economic factors particularly affect the cargo distribution pattern among the navigation areas of the respective rivers (upper, middle and lower), but have less impact on the cargo concentration levels among the inland ports belonging to the same river stretch.

Yang et al. (2014) found that political and economic events, such as the port reform and China's accession to the WTO exerted the biggest influence on the evolution of port traffic. Lee et al. (2018) summarized the impact of the Belt & Road Initiative (BRI) on maritime transport. These also seems to be applicable to Yangtze River ports.

During the 1990s, Jiangsu Province at the lower reach of Yangtze River seized the opportunity of the reform and opening-up policy and international industrial division adjustment, undertook the manufacturing transfer and many processing industrial parks were built. With the accession to WTO, the central government decentralized the port management to stimulate the growth of capacity to meet the rapidly increasing trade demand. Therefore, the container port network along the Yangtze River firstly experienced a process of decentralization in the early stage led by the ports along the lower reach. As more and more ports were built, the port capacity started to exceed demand since 2005 and the growth of the number of ports decreased. In the meanwhile, carriers increasingly opted to transship their cargo via a few ports, such as port with a good location with deep water (at the interface between two river segments) or with good port facilities. From 2006 to 2012, an opposite trend appeared: the growth pace slowed down and the concentration of container traffic among the ports was rising. Due to industrial upgrading and rising labor costs in the eastern region, the Chinese government implemented the "Western Development" strategy and "Rise of Central China" successively during the 2000s, which drove a move of manufacturing activities from the lower Yangtze River to middle and upstream locations. This consequently led to a strong growth of container traffic in the upper and middle Yangtze, and lowered the overall concentration level again. In contrast, with the slowdown of economic development in the lower Yangtze River, the latest inversed trend in the concentration level of the Yangtze can mainly be attributed to a wave of port integration processes in this region, see Zheng and Yang (2016) and the "Plan for the Overall Layout of Inland and Sea Ports in Jiangsu Province: 2015–2030".

The inland terminal network along the Rhine emerged in the early 1970s to facilitate container transport by barge between large industrial centers in Germany, France and Switzerland and the large seaports of Antwerp and Rotterdam. The middle Rhine is home to large cargo-generating chemical and pharmaceutical production sites such as the headquarters of chemical company BASF in Ludwigshafen, but also serves as gateway to some of the largest automotive clusters in Europe (e.g. Stuttgart). These industrial clusters generate large container flows and where among the first to adopt containerization in the early 1970s. In the 1970s and 1980s, the lower Rhine region - the Ruhr area in particular - was the industrial heartland of Germany with a strong focus on steel production and mining activities, which do not bring large container flows. However, the lower Rhine region gradually underwent a transformation process by developing itself into a prime region in Europe for modern supply chain management practices and European distribution activities. This partly explains the growing container volumes and stronger position of the lower Rhine reach in more recent decades. The inland port of Duisburg has been very instrumental in shaping this transformation process, but also other inland platforms benefited from the changing dynamics in European logistics.

4.3 Institutional and governance factors

Li et al., (2014) ascertained that the development of inland water transportation, as part of a socio-economic system, is significantly influenced by related government policies and institutional frameworks. There are both similarities and differences in the institutional structures and environment of the Yangtze River and Rhine River. For example, both rivers flow through different countries/provinces which have different laws, regulations and development plans. Administrative and political borders can increase inter-port competition and facility duplication and might undermine network concentration and rationalization. On the contrary, China has a strong central government and can easily implement a holistic strategy. In this section we discuss the role of institutional and governance factors in barge network development by using the concepts of variation, selection and retention as defined in section 2 of this paper.

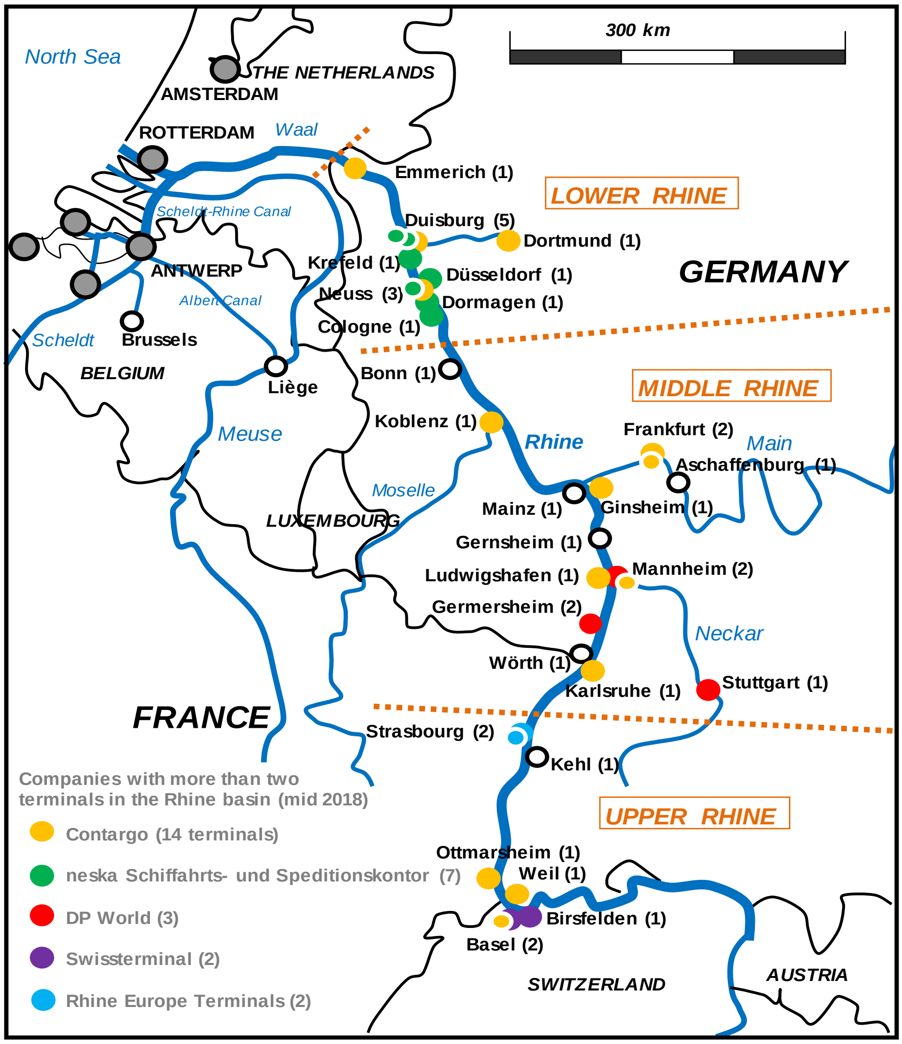
4.3.1. Selection

The selection mechanism is a competitive process that selects winners and losers in the inland port network and triggers the formation of competitive and or cooperative linkages between the agents in a barge network. Large logistics groups, shipping lines, seaport-based container terminal operating companies and other public or private parties might compete for controlling important inland terminals. When comparing selection processes on the Rhine and the Yangtze, some important differences are revealed.

Logistics groups have a strong position in barge terminals on the Rhine. Figure 9 shows the strong position of Contargo and Neska along the Rhine.

Contargo has a strong position in all three navigation areas. With a yearly throughput of 2.2 million TEU, Contargo is one of the leading container hinterland logistics networks in Europe. Contargo was founded in 2004 by the logistics group Rhenus AG & Co. KG. Contargo concentrated the activities of various Rhenus subsidiaries, mainly as a result of the 2006 merger between Combined Container Service GmbH & Co. KG (CCS) and Interfeeder BV. The beginnings of activities go back to 1976. Rhenus developed its position on the Rhine by combining greenfield terminal developments (such as Dortmund in 1989 and Duisburg-Rheinhausen in 2003) with the acquisition of existing operators. In 2012, Contargo took over six Wincanton terminals. Some other examples include the Unikai terminal in Wörth (1977) which was taken over in 2004 and the terminal of Alpina in Basel (1985) which came to Rhenus in 2001 with the takeover of all the activities of the SRN Alpina Group.

The neska group has a strong presence on the lower Rhine. Since 2015, neska is fully owned by Häfen und Güterverkehr Köln AG (HGK), which is owned by the Cologne Public Services Group (Stadtwerke Köln GmbH, part of Stadt Köln) 54.5%; Stadt Köln 39.2% and Rhein-Erft-Kreis 6.3%. HGK is one of the most important German railway companies. The strong position of logistics groups in terms of ownership of Rhine terminals is not new. Notteboom (2001) reported that the vast majority of the Rhine terminals have always been owned by large logistics players or their barge operating subsidiaries. Combined Container Service (CCS), one of Contargo's predecessors, was a key player on the Rhine which started up its first terminal in Ginsheim in 1976. This was followed by terminals in Ludwigshafen (1983), Koblenz (1986), Emmerich (1995), Valenciennes (1996), Frankfurt-Höchst (1998), Aschaffenburg (1999), Krefeld (2000) and Béthune (2004).



Note: Duisburg (5) implies there are five barge container terminals in Duisburg

Figure 9. Ownership of terminals on the Rhine (situation mid-2018)

Only few deep-sea terminal operators have a presence along the Rhine. Dubai-based DP World has developed a small terminal network on the Middle Rhine while Hong-Kong based Hutchison Ports operates one of the terminals in Duisburg, the involvement of these deep-sea terminal operators in river ports is mainly driven by a port regionalization strategy characterized by the establishment of 'extended gates' in the hinterland connected to their deep-sea terminals in Antwerp (DP World case) or Rotterdam (DP World and Hutchison Ports) using an integrated logistics service provision to cargo owners (Rodrigue and Notteboom, 2009; Veenstra et al., 2012). Other terminal operators with at least two terminals along the Rhine include Swissterminal AG, an independent family-owned logistics company and terminal operator based in Switzerland; Rhine Europe Terminals, the fully-owned terminal division of the Port Autonome de Strasbourg, controlled by the city of Strasbourg; and Duisburger Hafen AG (also known as the Duisport group) which has stakes in two of the five container terminals in Duisburg. The latter group is owned by the province of Nordrhein-Westfalen (66.6%) and the city of Duisburg (33.3%).

While the vast majority of the Rhine terminals is controlled by private companies with their proper logistics strategy and investment/divestment activities, the majority of the Yangtze River inland ports are owned by local public port corporations.

The case of lower reach of the Yangtze River is different from the middle and upper reaches. All the ports at the lower reach are under administration of Jiangsu Province and the density of ports is high at this reach. The port integration process in Jiangsu province is affected by the expansion of state-run Shanghai International Port Group (SIPG). For example, SIPG has invested in Taicang and already built it as a hub port for transferring containers from the upstream parts of the Yangtze River to the Yangshan deep-water terminal complex. SIPG has also invested in many river ports not only in Jiangsu province but all along the Yangtze River, in order to build its own container transshipment system. Table 3 shows the investments of SIPG in ports along the Yangtze River.

To realize the strategy, a batch of river-and-ocean intermodal ships is now under construction. The first type of the river-and-ocean intermodal ship can load 1,140 TEU and will sail from Shanghai to as far as Wuhan. These investments and technologies will reinforce the role of Shanghai as a gateway hub on the Yangtze River. Considering that more than 90% of Yangtze River containers are transshipped from Shanghai, SIPG's strategy is strongly shaping the Yangtze River container shipping network.

Table 3. SIPG investment in ports along Yangtze River

City	Company	Major business	Share Ratio	Year
Wuhan	Wuhan Port Group	Handling Storage,Transportation	36%	2005
Wuhan	Wuhu Port Container Terminal Co., Ltd.	Handling, Storage	56%	2005
Nanjing	Nanjing Port Co., Ltd	Terminal	51%	2005
Jiangyin	Jiangyin Sunan International Container Terminal Co.Ltd.	Terminal operation	97%	2006
Jiujiang	SIPG Jiujiang Port Co., Ltd.	Handling, Storage	68%	2008
Chongqing	Chongqing International Container Terminal CO., Ltd	Handling, Storage	76%	2011
Taicang	Taicang Port SP Zhenghe Container Terminals Co, Ltd	Handling	68%	2014
Wuhu	Wuhu Port Co., Ltd	Handling, transhipment	31%	2014
Chongqing	Chongqing Port Guoyuan Container Terminal Co., Ltd.	Handling	60%	2014
Yueyang	Hunan Chenglingji International Port Group	Handling, Transportation	74%	2014
Yibin	Yibin Port International Container Terminal Co., Ltd.	Handling, Storage, Delivery, Transportation	96%	2017

Source：Annual report of SIPG

In summary, the selection processes shaping terminal ownership vary greatly between the two rivers. The investment dynamics along the Rhine River are primarily led by large private logistics groups which often control barge operating companies. Seaport-related companies such as DP World have also acquired positions in the inland terminal landscape, although on a much smaller scale. The Yangtze River ports are run by (local) public port groups often in partnerships with SIPG, the public deep-sea port operator of Shanghai. This implies that the Yangtze River is characterized by a more direct and stronger link between seaport interests (i.e. the port of Shanghai) and the investment strategies in the inland terminal network. The different selection processes also can explain the different cargo concentration levels of the two rivers. Compared to the multiple stakeholders of the Rhine river case, SIPG has a dominant position in the Yangtze River. This market position enables the operator to influence cargo traffic distribution along the Yangtze River by selecting certain ports as its transshipment ports. Since 2014, SIPG has built Taicang as its inland container transshipment hub to Yangshan port by launching container shuttle services between Taicang and Yangshan. In 2018, the container throughput of Taicang ranked first in Jiangsu province. The cargo concentration level in the lower Yangtze shows an increase since then.

It should be noted that selection mechanisms at work in seaport systems can also affect the development trajectory of a container barge network. Barge networks are typically directly fed by only a few seaports, e.g. Rotterdam and Antwerp are the main seaports feeding the container network on the Rhine. The strategic actions of market players using these ports (e.g. in terms of choice of inland transport mode) and the competitiveness of these seaports affect the magnitude of barge container flows. Some examples applied to the ports of Antwerp and Rotterdam, the two largest container ports in Europe in volume terms:

- Over the past decades, container barge transport has developed into a very competitive hinterland transport mode for the ports of Antwerp and Rotterdam. The modal split figures in Antwerp’s container transport in 2017 amounted to 38% by barge, 56% by road and 6% by rail (Port of Antwerp statistical booklet 2017). The container modal split figures in Rotterdam are quite similar: 36%, 53% and 11% respectively (Port of Rotterdam statistics). Both ports have developed strategies to significantly increase the share of rail in inland transport. While these modal shift strategies are mainly aimed at reducing the reliance on trucks, a stronger competitiveness of rail can lead to a change in modal choice by users which might also negatively affect the growth potential for container transport by barge in relation to the hinterland regions in the Rhine basin;
- Port selection dynamics also play a role. In the past decade, Rotterdam and Antwerp have succeeded in significantly increasing their market share in container throughput, partly at the expense of north German container ports (Notteboom and De Langen, 2015). In case Rotterdam and Antwerp would lose container hinterland traffic to north German ports (Hamburg, Bremerhaven, Wilhemshaven) in the future due to changes in cargo routing and port choice behavior of actors involved in the container supply chains, then part of the flows to the hinterland regions along the Rhine would shift from barge transport to rail and or truck as the German ports do not have competitive barge links to the Rhine area. This would lower the growth potential for river container traffic on the Rhine. However, the impact of such changing competitive dynamics in seaport systems on the cargo concentration levels on the Rhine is difficult to measure as this will largely depend on which hinterland regions along the Rhine might move more cargo via the German ports instead of using Antwerp/Rotterdam.

4.3.2. Retention

Retention is a structural mechanism that causes new developments to reinforce the existing hierarchy in the barge network. Both barge networks are subject to retention mechanisms in the form of “preferential attachment” or “embedding”. The strong position of SIPG on the Yangtze River reinforces a process of retention. First, SIPG can use its strong credentials, experience and network effects to position itself as preferred partner each time a new inland terminal investment opportunity becomes available. Secondly, it would be very difficult for other public or private players to develop a terminal network of a similar scale or magnitude along the river. Therefore, SIPG’s position on the Yangtze remains unrivalled for the foreseeable future. Only a major government decision at central or Shanghai level (e.g. a merger of SIPG with another public entity) could lead to a new inland terminal landscape on the Yangtze.

The retention mechanism can lead to self-reinforcing effects whereby established inland ports become even more dominant in a barge network. The position of Duisburg on the Rhine provides a good example. Figure 10 shows the growing market share of Duisburg on the Rhine. This trend was initiated in the late 1990s when Duisport developed an aggressive and highly successful strategy to attract logistics activities and to forge partnerships which major gateway ports in Belgium, the Netherlands and Germany. This strategy and the associated marketing efforts led to strong preferential attachment processes among private investors in favor of Duisburg. In more recent years, Duisport has complemented its strategy by developing a strong focus on the growing China-Europe rail business in the context of the Belt and Road Initiative (BRI) of the Chinese government (Oltermann, 2018), as also reported by *South China Morning Post* in August 2018[1]. Duisport’s successful strategy has resulted in strong volume growth since the late 1990s which has greatly contributed to the observed strong increase of the concentration level in the lower Rhine. The prime position of Duisburg in the Rhine basin has generated preferential attachment and self-reinforcing effects whereby Duisburg can deploy its many ties with a wide range of market players to receive new ties. This process has contributed to the increase of the concentration level in the Rhine river.

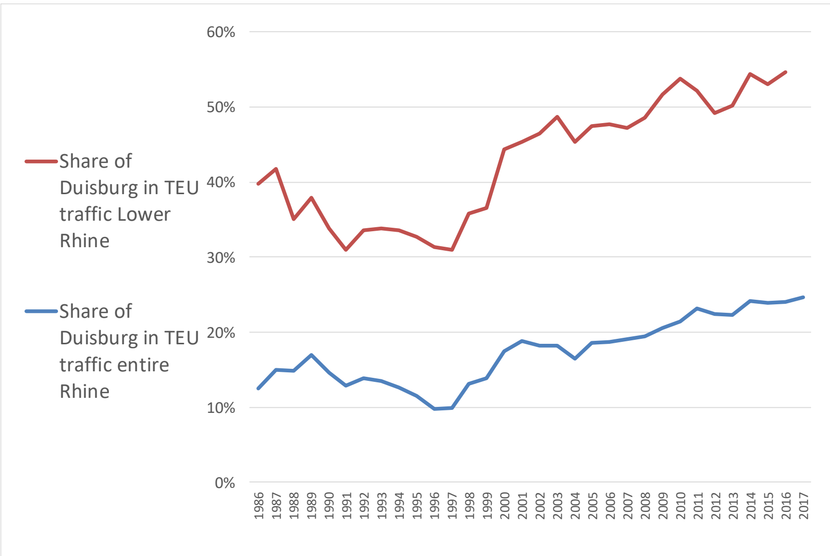


Figure 10. The market share of Duisburg in barge container traffic on the Rhine

[1] https://www.scmp.com/magazines/post-magazine/long-reads/article/2158959/germanys-china-city-how-duisburg-became-xi

4.3.3 Variation

Variation refers to mechanisms that enable novelty and path disruption in the development of an inland port system. The strategic behavior of and market-related possibilities offered to public and private agents are key triggers for variation to occur in an inland port system. Public (or state) agents can trigger variation processes by implementing major changes in spatial planning, terminal awarding processes, financial incentive schemes, etc. Private agents can significantly change the spatial and functional configuration of an inland port system through alliance formation and M&A activity.

It is interesting to observe that the European Union and its Member States advocate free market dynamics in inland port development characterized by little government guidance and intervention. In contrast, the central government of China exerts much stronger control over the spatial development of the inland port network along the Yangtze River to enhance economies of scale in inland terminal exploitation and to avoid destructive competition between terminals. This remarkable difference in approach has an impact on the inland port system. There are more inland ports on the Rhine than on the Yangtze, despite clear differences in navigable river length and in total container throughput handled (see earlier Figure 4). Consequently, inland terminals on the Yangtze on average handle much more cargo: an average of 777,000 TEU per inland port for the Yangtze in 2016 (426,000 TEU when Taicang and Nanjing are excluded) compared to a modest 88,000 TEU per inland port on the Rhine. The existence of more but smaller inland ports on the Rhine contributes to the overall lower cargo concentration level on this river when compared to the Yangtze River (see earlier Figure 6).

In 1998, China started a port system deregulation reform. Until March 2002, all the ports were under local administration, which meant that the local administration could determine if they needed to build new terminals. In 1998, 394 million RMB was invested into port construction along the Yangtze River, which was 7.6% more than in 1997 (China Ports Yearbook). With the appearance of more new ports and a slowdown of shipping traffic growth along the Yangtze River, the resource waste and environmental pollution gradually attracted great attention from the society. Given this background, the state council of China issued the "*Opinions on Promoting the Yangtze River Economic Belt (YREB) Development Based on the Golden Waterway*" and "*The National Plan for the Yangtze River Economic Belt Development*" in 2014 and 2016, respectively, in order to integrate the Yangtze River into a holistic economic and environmental governance. In response to this, a series of policies, regulations and measures regarding port integration have been issued by regional governments. For example, Jiangsu Province started to implement the "*Jiangsu Province Port Layout Plan 2015 – 2030*". The goal of the plan is to optimize the port resource in Jiangsu Province. In the plan, Nanjing is defined as the "regional shipping logistics center", while Taicang is "an important component of Shanghai international shipping center". In addition, the Belt and Road Initiative stimulated the development of transcontinental rail in deep hinterland (Lee, 2018; Wei et al., 2018). All these policies imply that the middle and upper reaches of the Yangtze River will continue to see few ports, and that the relationship among these ports is of complementary nature (Liu et al., 2018). The provincial governments in principle coordinate the resource allocation so that only one or two hub ports can develop in the same river segment, such as Chongqing in the upper reach (with two very large terminal complexes, i.e. Cuntan and Guoyuan), Wuhan in middle reach and Nanjing on the lower Yangtze. Table 4 shows the major policies with regard to port integration. These measures boost the increase of container cargo centralization along the Yangtze River after 2012, as listed in Table 4.

Table 4. Integration measures implemented by governments in China

Policy maker	Measures	Objectives	Year
State Council	Opinions on Promoting the Yangtze River Economic Belt (YREB) Development Based on the Golden Waterway	Integration of the Inland Waterway Transportation (IWT) into a holistically economic and environmental governance	2014
	The National Plan for the Yangtze River Economic Belt Development		2016
Chongqing Municipality	Opinions of Chongqing Municipal Government on Speeding up the Construction of Chongqing Shipping Center	An integrated port cluster centered by Chongqing	2014
Sichuan Province	Opinions of Sichuan Provincial Government on the Implementation of National Strategy of YREB	Integrate Yibin and Luzhou as transshipment hub	2014
Hunan Province	Formation of the Chenglingji International Port Corporation	Integrate Yueyang port and Changsha port	2016
Hubei Province	Formation of Wuhan new port Administration Committee	Integrate the ports of Wuhan, Ezhou, Huanggang, and Xianning	2010
Anhui Province	Plan for Waterway Construction in Anhui Province	Integrate port resources by building a unified platform for port management and operation	2017
Jiangsu Province	Plan for the Overall Layout of Inland and Sea Ports in Jiangsu Province	Integrate municipal state-owned port companies.	2015

The concentration of container traffic is further catalysed by the strategies of Shanghai International Port Corporation (SIPG) at the mouth of the Yangtze River. As it grows, SIPG started to invest in ports in different reaches of the Yangtze River.

The majority of terminal operators on the Yangtze are state-run companies, which further facilitates the practical implementation of policies designed by government entities at various geographical scales (central, provincial, local). Each Chinese governmental department makes its own five-year plan subordinated to that of the central government. In each five-year transportation plan made by the Ministry of Transportation, the port development of the Yangtze River is planned, and its strategy of development is addressed. Besides these plans, two policies, "*Opinions on Promoting the Yangtze River Economic Belt (YREB) Development Based on the Golden Waterway*" in 2014 and "*The National Plan for the Yangtze River Economic Belt Development*" in 2016, were issued. Within this government-oriented environment, the development of the Yangtze River does not primarily follow the market, and the 'windows of opportunity' are created by the government. One of the most important critical junctures, the deregulation reform of the port management structure, was led by the central government and influenced ports of the Yangtze River profoundly.

The Chinese controlled approach to inland network development contrasts with the Rhine River where broadly defined spatial development plans at provincial or national level give ample room to local port authorities and private actors to roll-out investment strategies in anticipation of specific market opportunities. Many private actors show ambitions to engage in inland port activities and to develop associated terminal networks. The interplay among market players during consecutive waves of 'windows of opportunities' for inland terminal development up to now resulted in 38 inland container terminals in 22 different inland ports, as shown earlier in Figure 8. However, variations exist in the institutional settings among inland ports of the Rhine. For example, a growing dualism is observed between larger inland ports managed by full-fledged port authorities (such as Duisburg) and a large set of smaller inland terminal facilities often developed by local and international logistics players. This dualism has particularly affected the cargo concentration level on the lower Rhine, where Duisport has succeeded in establishing itself as the hub port for the entire region.

5. Conclusions

With this paper, we presented a comparative empirical analysis focusing on container shipping (barge) network development in the Yangtze and the Rhine in order to understand if there exists a general evolutionary pattern of inland river container barge network development.

The contribution of this paper can be extracted when examining the current state of barge network research as presented in the literature review in this paper.

First, only few studies combine the development of (inland) port systems in terms of configuration transformation with an explanatory analysis of this transformation. This study asserted that the formation of barge networks on rivers and associated inland port systems is subject to a complex set of influencing factors and mechanisms. By presenting both descriptive and explanatory approaches to barge network development, this paper identified and empirically demonstrated the factors influencing cargo dynamics in barge networks. By following this dual approach, this paper can help readers to comprehensively and thoroughly understand the general evolution model of container shipping (barge) networks in inland river systems.

Second, the existing spatial models on inland port system development portray a high degree of path dependency in the development of inland ports at a regional scale and suggest that container barge shipping networks would follow a similar evolutionary path. The analysis of the Yangtze and Rhine rivers demonstrates that, while similarities can be observed, development processes also show a certain degree of contingency due to differences in nautical/geographical conditions, macro-economic settings and strategies and actions of public and private actors. More than once, path disruption in cargo concentration levels was observed.

Third, with the exception of the largely qualitative work of Notteboom (2007), extant literature focuses on single river systems in a specific part of the world. This paper is the first study to present a comprehensive comparative empirical analysis focusing on the container shipping (barge) network in the Yangtze and the Rhine, thereby supported by extensive datasets on both river basins. While the results are location-specific and time-specific and subject to a specific economic system with a different mix of economic actors and the government, it sheds light on how differences in such a mix across regions might lead to some level of disparity among inland port systems. Further research on other (smaller) barge networks around the world can be grounded on these insights in view of further specifying and explaining differences between regional development trajectories.

We obtained the following findings through both descriptive and explanatory analysis.

The descriptive analysis revealed that, although the container traffic flows of the Yangtze and the Rhine have a similar overall development trend, the traffic distribution along different river stretches is different. For the Yangtze River, the sequence of port development is from downstream to upstream, whereas for the Rhine the development started on the middle reach. The relative importance of the ports in the middle and upper reaches is rising in the Yangtze River, but declining in the Rhine River. In the early stage, the two rivers showed a similar concentration pattern. However, the development paths of the concentration levels clearly diverged afterward.

The explanatory analysis focused on three groups of factors influencing barge network development, i.e. nautical/geographical, macro-economic and institutional/governance factors. The geographical features of both rivers determined their container shipping networks and cargo concentration levels. The overall and regional economic development affect the cargo distribution patterns among various stretches but only have minor impacts on the cargo concentration levels of the ports in the same stretch. The different institutional structures and environments between the Yangtze and the Rhine led to respective development trends and concentration levels in recent years.

We identified selection, retention and variation mechanisms as instrumental to the mix of path dependency and contingency in the development of the barge networks of both rivers and to the similarities and differences between the development paths in both rivers. The selection process resulted in a significant difference in terminal ownership. The ports along the Rhine are primarily operated by large private logistics groups, while the Yangtze River ports are run by public port groups. Also, seaport competition dynamics and modal choice/selection considerations in hinterland traffic can affect the development trajectory of inland barge networks. The retention mechanism leads to self-reinforcing effects leading to dominant positions, such as the position of Duisburg along the Rhine. The variation mechanism is mostly triggered by public agents. Due to the strong governmental influence in the case of the Yangtze River, the variation forces are more obvious than in the Rhine River.

The three mechanisms sometimes imposed their impacts simultaneously. For example, Shanghai has been given a priority in developing container transhipment in the Yangtze River through national strategy. Due to the policy backstop, SIPG dominates the transhipment of container cargo in the Yangtze River. After the dominant position is confirmed, SIPG further utilized various strategies including investment in inland ports to maintain its position, which also has a great impact on the development in and cargo concentration levels of the Yangtze River.

While the scope of the study was restricted to the two largest container barge networks in the world, the three explanatory factors and the interplay among them are expected to also shape the development trajectory of smaller inland rivers. The external validity of our findings can be tested in future research by focusing on other rivers. We expect that smaller rivers will feature some distinctive characteristics in their development path. For example, their smaller cargo base might lead to smaller container terminals or fewer (but relatively large) terminals, partly also depending on the distribution pattern of economic activity along the river stretches. As regards governance, it might be interesting to analyse whether there are differences in terminal ownership when comparing large rivers and smaller rivers, for example in terms of local vs. global players, multi-terminal ownership vs. single-terminal ownership and the involvement of deepsea terminal operators in inland terminals.

This paper increases the understanding of inland port system development. We hope the findings of this paper can help relevant inland river stakeholders, including policy makers, port operators and so on, with strategy formulation and implementation in the field of inland port system development. As a future extension, New Economic Geography (NEG) can be a notable method to quantify the mechanism of the evolution of river port systems. The existing NEG models relevant to continuous space consider a one-dimension space, which is applicable to the river system. The NEG models based on the general equilibrium approach have a higher explanation power than the conceptual model but would need massive data to validate.

References

Brooks, M.R. and Cullinane, K. eds., 2006. Devolution, port governance and port performance. *Research in Transportation Economics*, 17.

Brooks, M.R., Cullinane, K.P. and Pallis, A.A., 2017. Revisiting port governance and port reform: A multi-country examination. *Research in Transportation Business & Management*, 22, 1-10.

Ducruet, C., Notteboom, T., de Langen, P., 2009. Revisiting inter-port relationships under the new economic geography research framework. In: Notteboom, T., Ducruet, C., de Langen, P. (Eds.), *Ports in Proximity: Competition and Coordination among Adjacent Seaports*. Ashgate, Alderschot, pp. 11–28.

Frémont, A., Franc, P. and Slack, B., 2009. Inland barge services and container transport: the case of the ports of Le Havre and Marseille in the European context. *Cybergeo: European Journal of Geography*, paper no. 437, 2-17

Glückler, J., 2007. Economic geography and the evolution of networks. *Journal of Economic Geography*, *7*(5), 619-634.

Jacobs, W. and Notteboom, T., 2011. An evolutionary perspective on regional port systems: the role of windows of opportunity in shaping seaport competition. *Environment and Planning A*, 43(7), 1674-1692.

Konings, R., 1999. Container-Binnenschiffahrt: Neue Umschlagtechniken und Terminals spielen Schlüsselrolle, *Binnenschiffahrt, Zeitschrift für Binnenschiffahrt und Wasserstrassen*, 1, 48-50.

Lee, P. T-W., 2018. Connecting Korea to Europe in the context of the Belt and Road Initiative, *KMI International Journal of Maritime Affairs and Fisheries*, 10(2), 43-54.

Lee, P. T-W, Hu, Z-H, Lee, S-J, Choi, K-S, and Shin, S-H., 2018. Research trends and agenda on the Belt and Road (B&R) initiative with a focus on maritime transport, *Maritime Policy & Management*, 45(3), 282-300.

Li, J.Y., Notteboom, T.E. and Jacobs, W., 2014. China in transition: institutional change at work in inland waterway transport on the Yangtze River. *Journal of Transport Geography*, 40, 17-28.

Li, J.Y., Notteboom, T.E. and Wang, J.J., 2017. An institutional analysis of the evolution of inland waterway transport and inland ports on the Pearl River. *GeoJournal*, 82(5), 867-886.

Liu, N., Gong, Z., & Xiao, X., 2018. Disaster prevention and strategic investment for multiple ports in a region: cooperation or not. *Maritime Policy & Management*, *45*(5), 585-603.

Nelson, R.R. and Winter, S.G., 2002. Evolutionary theorizing in economics. *Journal of Economic Perspectives*, *16*(2), 23-46.

Ng, A.K., Ducruet, C., Jacobs, W., Monios, J., Notteboom, T., Rodrigue, J.P., Slack, B., Tam, K.C. and Wilmsmeier, G., 2014. Port geography at the crossroads with human geography: between flows and spaces. *Journal of Transport Geography*, 41, 84-96.

North, D., 1990. Institutions and their consequences for economic performance. *The limits of rationality*, 383-401.

Notteboom, T.E., 2001. Spatial and functional integration of container port systems and hinterland networks in Europe. *ECMT report Land Access to Sea Ports,* Report no. 113, European Conference of Ministers of Transport, Paris.

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

Notteboom, T., 2007. Container river services and gateway ports: Similarities between the Yangtze River and the Rhine River. *Asia Pacific Viewpoint*, 48(3), 330-343.

Notteboom, T., 2017. Maritime gateways and barge connectivity: container barge transport on the Rhine. In *The Rhine: A Transnational Economic History*. Nomos Verlagsgesellschaft mbH & Co. KG., pp. 311-334.

Notteboom, T., De Langen, P.W., 2015. Container port competition in Europe, in: Lee, C.-Y., Meng, Q., Handbook of Ocean Container Transport Logistics – Making Global Supply Chain Effective, International Series in Operations Research & Management Science, Vol. 220, Springer International Publishing, 75-95

Notteboom, T. and Konings, R., 2004. Network dynamics in container transport by barge. *Belgeo. Revue belge de géographie*, 4, 461-478.

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

Oltermann, P. 2018. Germany's 'China City': how Duisburg became Xi Jinping's gateway to Europe, The Guardian, 1 August 2018

Portopia, 2016. *Towards a competitive and resource efficient port transport system*. Collaborative Project, 7th Framework Programme European Commission, Grant Agreement no. 605176, www.portopia.eu .

Rhoades, S.A., 1993. The Herfindahl-Hirschman index. *Fed. Res. Bull.*, *79*, p.188.

Rimmer, P.J. and Comtois, C., 2009. China’s container-related dynamics, 1990–2005. *GeoJournal*, *74*(1), pp.35-50.

Rodrigue, J.P. and Notteboom, T., 2009. The terminalization of supply chains: reassessing the role of terminals in port/hinterland logistical relationships. *Maritime Policy & Management*, 36(2), 165-183.

Strambach, S., 2010. Path dependence and path plasticity: the co-evolution of institutions and innovation–the German customized business software industry. In *The handbook of evolutionary economic geography*. Edward Elgar Publishing.

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

Veenstra, A., Zuidwijk, R. and Van Asperen, E., 2012. The extended gate concept for container terminals: Expanding the notion of dry ports. *Maritime Economics & Logistics*, 14(1), 14-32.

Wang, C. and Ducruet, C., 2012. New port development and global city making: emergence of the Shanghai–Yangshan multilayered gateway hub. *Journal of Transport Geography*, 25, 58-69.

Wei, H., Sheng, Z., and Lee, P. T-W., 2018. The role of dry port in hub-and-spoke network under Belt and Road Initiative, *Maritime Policy & Management*, 45(3), 370-387.

Wiegmans, Bart, Patrick Witte, and Tejo Spit., 2015. Characteristics of European inland ports: A statistical analysis of inland waterway port development in Dutch municipalities. *Transportation Research Part A: Policy and Practice*, 78, 566-577.

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

Wiradanti, B., Pettit, S., Potter, A. and Abouarghoub, W., 2018. Ports, peripherality and concentration–deconcentration factors: a review. *Maritime Business Review*, 3(4), 375-393.

Yang, D., Chin, A.T. and 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.

Yang, D., Wang, K.Y., Xu, H. and Zhang, Z., 2017. Path to a multilayered transshipment port system: How the Yangtze River bulk port system has evolved. *Journal of Transport Geography*, *64*, 54-64.

Zheng, J. and Yang, D., 2016. Hub-and-spoke network design for container shipping along the Yangtze River. *Journal of transport geography*, *55*, 51-57.