Spatial–temporal evolution of the port–hinterland relationship: A case study of the Midstream Yangtze River, China

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Abstract
Most scientific attention on port studies centers on deep sea ports, especially container ports. In this paper, in contrast, attention is focused on the spatial–temporal development of inland waterway ports on the Midstream Yangtze River from 2001 to 2013. The aim of this study is to assess two relevant and complementary questions of the hinterland evolution: its geographical extent and the coordination relationship with the inland port. To conduct the study, it was necessary to first identify the boundaries of the ports' hinterlands within the given timeframe. Then, the coupling coordination degree model was introduced to explore the underlying relationship between the port service and hinterland economy. Furthermore, to better depict the intricate economic characteristics of the hinterland, the development stage theory was applied in the models. The results highlight the emergence of a discontinuous hinterland at Wuhan Port and its reinforcement of primacy with respect to fierce hinterland rivalry. It also demonstrates that an interplay between major ports and their corresponding hinterlands evolves from the transitional stage, characterized by lagging port service, to the multi-stage, wherein the supply of ports partly outstrips hinterland demand.
INTRODUCTION

Since the adoption of containerization in international trade, the dynamics of transportation and logistics activities have been nothing short of astounding and all-encompassing. Containerization and intermodality have progressively eroded the traditional hinterland paradigms by expanding hinterland coverage and the associated shift from captive hinterlands to shared or contestable hinterlands, which has transformed the perception of port markets from monopolistic or oligopolistic to competitive (Ferrari, Parola, & Gattorna, 2011). Within this context, the level of port activity corresponds to the dynamics of the hinterlands to which they are connected. Additionally, inland transport costs have constituted a significant proportion of logistics costs, and most bottlenecks occur in the hinterlands, such as congestion, insufficient infrastructure, and problems with handling barges, trains, and trucks (van der Horst & van der Lugt, 2011). Many municipalities within the hinterlands are confronting spatial challenges with regard to accommodating conflicting port and urban functions (see e.g., Wang, 2014; Wiegmans & Louw, 2011; Witte, Wiegmans, van Oort, & Spit, 2014). Accordingly, there is renewed interest in the coordination in hinterland container transport from the interorganizational perspective (De Langen, Van der Horst, & Konings, 2006; Van Der Horst & De Langen, 2008; van der Horst & van der Lugt, 2011). Such studies are valuable, but they do not provide a basis for understanding the influence of economic development and industrial structure on the port system. Considering the significance of the macroeconomy to contemporary hinterlands, the relationship between a seaport and its local economy region has been fruitfully examined in economic geography. One element of the relationship is how a seaport contributes to the economic development of its hinterland (Dooms, Haezendonck, & Verbeke, 2015; Yochum & Agarwal, 1987), and the other is the role of hinterland in seaport development (Notteboom & Rodrigue, 2007). However, little research on this topic involves the coupling coordination relations between port and hinterland economy with the parallel analysis of hinterland demarcation in the regional port system.

The same observation applies to the literature that specifically deals with inland waterway ports. In line with this stream of research, we focus on the spatial–temporal development of hinterlands of the river port system along the Midstream Yangtze River (MYR). Despite the Three Gorges Project located in Yichang and the economic boom in megacity regions in MYR, little is known about these ports and their corresponding hinterlands as compared to Chinese seaports, which have been studied by various authors (see e.g., Cullinane, Teng, & Wang, 2005; Yang, Luo, & Ji, 2016) and inland ports in other parts of China and the world (see Wang and Slack [2000] on the Pearl River Delta; Comtois and Dong [2007] on the Yangtze River Delta; Notteboom [2007a] for river ports on the Rhine River; and Wiegmans, Witte, and Spit [2015] for river ports in Netherlands). A river port system is widely accepted as a corridor consisting of a set of continuous and discontinuous areas, all positioned along a river or waterway (Veenstra & Notteboom, 2011). In this context, we define an inland port as a place along a waterway with facilities for loading and unloading ships. It is different from the concept as used in the American context (Witte et al., 2014), known as a larger freight site with mostly rail terminals (and sometimes water). In China, such a rail-oriented node is generally known as a dry port or land port (and not as an inland port). Obviously, seaports are connected to a large set of overseas seaports and thus develop “foreland-based regionalization” (Rodrigue & Notteboom, 2010), while inland port systems are typically fed by only a few large gateway ports. Additionally, the structure of freight flows is generally treelike with limited or no lateral connections between the branches. Moreover, inland ports have stronger captive hinterlands than seaports since there are many of them, and they are much closer to the origin/destination. Between the shipper and the inland port is a truck journey, which is where a lot of the time and cost comes from. It is therefore of great benefit to investigate the evolution of the river port system in MYR by answering the following research questions: (a) Does
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the spatial evolution of hinterlands, as observed in seaport systems, work in a similar way in river port systems? (b) What are the features of the dynamic trends in the development of the coupling of inland ports and the hinterland economy? This study aims to address these questions by first reviewing the development of port hinterland research and then conducting an empirical analysis.

Moreover, this study attempts to augment the existing literature on port systems by adapting port development models to river ports. It will construct a framework to combine the analysis of the hinterland's geographical extent and the coordination relationship between port and hinterland economy. The framework is mainly based on the field model and coupling coordination degree model (CCDM), which will be detailed in the following sections. The remainder of the paper is organized as follows. In Section 2, the port–hinterland development is theorized. In Section 3, an analytical framework for the coordination relationship of the river port system is developed. Subsequently, in Sections 4 and 5 respectively, the analysis of hinterland demarcation and the coupling coordination relationship between port and hinterland economy is presented. Based on this analysis, Section 6 summarizes the major findings and highlights the conclusions that can be drawn.

2 | THEORIZING ON PORT–HINTERLAND DEVELOPMENT

Starting in the 1960s, the literature began to tackle the issue of port–hinterland relationships (Taaffe, Morrill, & Gould, 1963), although some seminal studies date back even earlier (Sargent, 1938). Nevertheless, the interest in the issue of hinterland development waned in the late 1980s, largely due to dematerialization and containerization (Notteboom & Rodrigue, 2007). It is widely acknowledged that containerization and innovations in the inland transport system lead to a time–space convergence and prompt market players to reconfigure and synchronize liner service schedules and associated hinterland networks rather than depending purely on the proximity of ports. This fierce competition makes it incongruous to view the port hinterland as a static concept. Despite the developments noted above, some authors believe that the hinterland continues to play a critical role in container port development (Fleming & Hayuth, 1994; Gouvernal, Rodrigue, & Slack, 2012). They highlight that delimiting the hinterland is the first step for stakeholders and policy makers involved in decision making regarding both the design of port strategies and infrastructure layout (He, Yin, Zheng, & Gao, 2019; Moura, Garcia-Alonso, & Salas-Olmedo, 2017; Wang, Meng, & Miao, 2016). While both port selection and hinterland economy are topics of great interest, the literature that provides a spatial analysis of both aspects and the underlying relationship in the river system is much scarcer.

In general terms, the port hinterland comprises the geographical sphere of influence where the port draws the majority of its business (Notteboom, 2007a). However, it must be borne in mind that the concept of hinterland is dynamic, with Wilmsmeier, Monios, and Lambert (2011) defining it as “the area that can be reached at a cheaper cost or shorter time than from another port.” Travel time is thus a better proxy than distance to depict the hinterland scope since it efficiently reflects the various frictions of distance resulting from technology and infrastructure improvements (He, Gao, Sun, & Lau, 2017; Kerkman, Martens, & Meurs, 2017). Models of spatial interaction (e.g., the gravity model, Huff model, and field model) based on travel time and masses (attractiveness) can simultaneously analyze the influence of both spatial and transport network characteristics. This allows the spatial scope of the hinterland with features of local continuity and overall discontinuity in space to be identified (Garcia-Alonso, Martinez-Pardo, & Vallejo-Pinto, 2016). When it comes to the construction of various distance matrices between ports and hinterlands, abstracting municipalities or counties into a centroid point or geometric center is a common processing strategy. However, using administrative divisions as spatial subunits could distort the value of accessibility. Besides, the single indicator (e.g.,
container throughput) applied as an influence index in existing models is ineffective in reflecting the port’s performance. Thus, in order to advance the research, this study proposes an adapted version of the field model that includes the travel time and port’s integrated value as explicative variables combined with the cost distance tools on ArcGIS 10.1.

In this study, the hinterland is clearly consistent with Notteboom and Rodrigue’s (2007) concept of “macro-economic hinterland,” which goes beyond the consideration of port clients, both existing and potential, within a regional setting. Compared with the hinterland identified by the origin/destination location of the shipments traversing the port, it places more emphasis on the interplay between the port and hinterland economy. The hinterland of seaports has been shown in previous studies to be reshaped by powerful economic forces in the globalization context (Notteboom, 2007b; Shi & Li, 2016). Imbalanced international trade led by the economic environment imposes a subtle influence on traffic flows and completely oversteps the level of the port’s intervention. In terms of inland port systems, the local economy plays a similar role in market segmentation. For one thing, governments typically tend to follow macroeconomic objectives and deploy infrastructural facilities as a prime planning tool in this context (Comtois, Slack, & Sletmo, 1997). Hayuth (1982) has proved that exogenous economic factors are a shaping factor and that “where centralized governments control port operations, government policy favoring one port over another can affect the size of a port hinterland.” For another, the generated wealth in each hinterland area can be read as a driver for both exports and imports because a high level of employment and high salaries can guarantee good purchasing power (Ferrari et al., 2011). Like their deep sea port counterparts, the relationship between inland ports and hinterland development is obviously present. It can be observed that current research has created conceptual models for the interaction between port and hinterland economy, such as gray correlation analysis, data envelopment analysis, and the structural equation model. Also, based on synergetic theory, the CCDM was recently applied to ports in the Yangtze River Delta by Ye, Cao, Jiang, and Wang (2017). Although some interesting implications were presented in these studies, it is noted that most are analyzed without hinterland demarcation research and only focus on seaports.

Consequently, it is timely to analyze the coordination relationship within the influence sphere of inland ports and the evolution of that relationship over time, both for the design of its strategy and for a better understanding of regional economic integration. With this task in mind, this study considers the relationship as a systematic issue and introduces the CCDM to explore the mutual interaction, influence, and restriction between the port subsystem and hinterland economic subsystem within a given region. Apparently, a definite hinterland boundary obtained through spatial interaction models is the prerequisite for the construction of this model. The combination of the field model and CCDM not only allows for the assessment of a specific port’s spatial development evolution over time and the comparison of the leadership change of a range of competing ports in the hinterland side but also the understanding of the interaction in the port–hinterland system. How the models have been adapted and how the variables have been estimated are questions to be explained in the following section.

3 | MATERIALS AND METHODS

3.1 | Geographic sample: Ports and hinterlands

As the third longest river in the world, the Yangtze River is approximately six thousand three hundred kilometers long in total. About two thousand eight hundred kilometers are navigable for cargo vessels, from Shuifu Port in Yunnan to the estuary in Shanghai. In the “Outline of the Yangtze River Economic Belt Development Plan” recently implemented by the central state, the Yangtze River is regarded as a “golden waterway” that plays an important role in the strategy to develop the central
and western provinces of China. Meanwhile, megacity regions in the MYR are officially positioned as a new growth pole of China's economic development and have begun to welcome massive (foreign) investments. For this particular case study, the MYR refers to the reach from Yichang to Jiujiang, with the basin area of six hundred eighty thousand square kilometers. Among more than one hundred thirty ports located in this region, we selected eight major inland ports to study their hinterland development within megacity regions in the MYR at the county level. Such ports comprise a very significant sample in relation to the selected hinterland, as they respectively acquired 65 and 98% in cargo and container throughput of the three provinces by the end of 2013. Due to the data availability, districts under municipal jurisdiction of each county were merged together, except for the Caidian, Jiangxia, Xinzhou, and Huangpi districts of Wuhan. Gongqingcheng city was also excluded because it was newly established in 2010. Finally, one hundred seventy-five county units were obtained, and the specific study area is illustrated in Figure 1.

3.2 Data collection and preprocessing

Based on the existing research conditions and availability of data, the time scale was designated as 2001–2013 in this paper, in consideration of the port system deregulation reform from the late 1990s up to 2003 as well as China's entrance into the World Trade Organization (WTO) in 2001. Furthermore, the examined data and statistical data were taken as the main data source. The data regarding the socio-economic attributes of hinterlands were originally collected from the Statistical Yearbook of Hubei, Hunan, Jiangxi province, and some counties in the area. Port throughput data were

**FIGURE 1** Location of the study area
mainly obtained from the China Ports Yearbook. Additionally, the relevant administrative boundary and river boundary data were drawn from the 1:1,000,000 ratio vector data from the National Basic Geographic Information Center. To eliminate the influence of different indicators’ magnitude, dimension, and positive or negative orientation, the raw data needed to be standardized by the min–max normalization method. The specific calculation process is as follows:

positive indicator:

\[ x'_k = \frac{\left( x_k - \min_k x_k \right)}{\left( \max_k x_k - \min_k x_k \right)} , \]  

(1)

negative indicator:

\[ x'_k = \frac{\left( \max_k x_k - x_k \right)}{\left( \max_k x_k - \min_k x_k \right)} , \]  

(2)

where \( x_k \) represents the value of indicator \( k \), \( \max_k x_k \) and \( \min_k x_k \) indicate the maximum and minimum values of the indicator \( x_k \), respectively. To ensure a bigger system index score and represent a better index level, two methods were chosen—the positive indicator and the negative indicator—for data processing.

3.3 | Analysis measurement

The selected topic falls under the stream of spatial interaction and coordination development within the framework of systematic studies. Both topics are realized through frequent business and movement of freight or people between port and hinterland. In this respect, a preliminary determination of the indexes was conducted and a general framework was developed to characterize the spatial consequences of port choice together with a quantitative evaluation of the relationship between port service and hinterland economy. This process particularly emphasizes the actual situation of MYR and constructs the CCDM based on hinterland demarcation and economic development stage divisions, as explained in detail in Sections 3.3.1–3.3.4.

3.3.1 | Evaluation of inland port and hinterland

Data problems often arise due to measurement issues related to the quay or terminal which can be under (or outside) the jurisdiction of the inland port authority. So this study concentrated on relating the hinterland economy of inland waterway ports to their development in terms of cargo throughput. Drawing on the index system used by other scholars (see e.g., Deng, Lu, & Xiao, 2013; Song & van Geenhuizen, 2014), taking into account the operability and scientific nature of the evaluation index, quantitative indicators that are easily found in the current China Statistical Yearbook and China Port Statistical Yearbook were selected. Then, the indicators were further selected through a comparison of the correlation coefficients and significance levels. Finally, a comparable and adaptive indicator system consisting of 2 hierarchies and 10 indicators was formulated (shown in Table 1). Suppose \( x_1, x_2, \ldots, x_m \) represent the indexes of the inland port subsystem, and \( y_1, y_2, \ldots, y_n \) represent the indexes of the hinterland subsystem on the county level, then

\[ V_{it} = 100 \times \sum_{m=1}^{p} w_m x'_m \] and

(3)
where \( V_{ct} \) and \( V_{ct} \) are the integration values of inland port \( i \) and the certain county \( c \), respectively, in time period \( t \); \( x'_m \) and \( y'_n \) are the standardized values of \( x_m \) and \( y_n \) obtained by Equation (1) or (2); \( w_m \) and \( w_n \) are the weights of \( x_m \) and \( y_n \), respectively, which can be calculated by the structure entropy weight method.

The structure entropy weight method is designed to overcome the limits of the subjective evaluation method and the objective evaluation method. The basic idea of this synthetic evaluation method is to analyze the indexes of the assessment system and the interrelationship between them and then to classify the indexes into independent hierarchical grades (Cheng, 2010). It began with the collection of 15 participants’ expertise in accordance with the procedures and requirements of the Delphi method (Dalkey, 1969). The panel of experts were mainly academic specialists with extensive experience in the field of port research. The entropy value was then further calculated using the entropy theory (Shannon, 1948) to eliminate noisy data and reduce uncertainty expert ranking, which is called blind degree (uncertainty) analysis. The raw data (2001–2013) describing the 10 indexes of the port–hinterland system in this research were processed by the structure entropy weight method (Table 1), and the related values were subsequently calculated. The detailed calculation process can be found in Cheng (2010).

### 3.3.2 Demarcating the scope of the hinterland: Field model

Since ports have become links in a logistics chain, hinterland access is now perceived as a key success factor of inland ports. That is, shippers’ port selection does not depend solely on the characteristics of the port itself but also on the overall performance of the entire transportation process. The field model uses “field” to describe changes of the force from the center to edge, and delineates spheres of influence by obtaining the influence indicators and spatial expression of field (Wang, Deng, Liu, & Wang, 2011). Traditionally, diffusion effect of the field model is conducted in an ideal space, resulting in an...
overlook of the anisotropy of field extension in space. Thus, this research proposes an improved field model based on the construction of integrated indicators and the measure of hinterland accessibility by minimum travel time. The adapted field model can reveal the current role of transport in drawing hinterland market share among the selected ports.

By the end of the given timeframe, the percentages of the goods transported in the three provinces by road, waterways, and railway were 84.0, 12.5, and 3.5%, respectively, meaning that almost all goods in study areas were delivered through road and waterways. Aviation in the MYR mainly concentrated on connections outside the region as passenger transport. Consequently, the time cost for landside traffic is estimated in Table 2, excluding air transport. Given regional heterogeneity, the grid concept in GIS was introduced, and each grid corresponds to a spatial geographic region of 0.3 km by 0.3 km on the earth surface based on the actual situation of MYR and the spatial resolution. Borrowed the concepts from physics, the port system would be known as the “port field.” The field is a limited space around the original core port, including points, lines, and polygons, which have external influence, usually abstract and virtual, on the space encircling them (Jiao & Liu, 2010). Each point in the field is assigned a quantity, namely field intensity, representing the external effect score of the port. An intensity function is used to describe the changing rule of geographic field intensity, which is defined in Equation (5). According to the maximum membership principle (Pan & Liu, 2014), the main idea of this methodology is that if the total field intensity of a given port in one county is the maximum, then the county lies within this port’s hinterland. The model is expressed as follows:

\[ F_{igt} = V_d D_{igt}^{\lambda} \]  \( (5) \)

\[ F_{ict} = \sum_{g=1}^{u} F_{igt} \]  \( (6) \)

\[ F_{ct} = \max_i F_{ict} \]  \( (7) \)

where \( F_{igt} \) is the field intensity of port \( i \) at grid cell \( g \) in period \( t \); \( F_{ict} \) is the total field intensity of port \( i \) in all grid cells within a county \( c \); \( F_{ct} \) is the maximal field intensity in certain county \( c \); \( V_d \) is the

<table>
<thead>
<tr>
<th>Object</th>
<th>Speed (km/h)</th>
<th>Time cost (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway</td>
<td>90</td>
<td>0.68</td>
</tr>
<tr>
<td>Expressway</td>
<td>100</td>
<td>0.60</td>
</tr>
<tr>
<td>National highway</td>
<td>80</td>
<td>0.75</td>
</tr>
<tr>
<td>Provincial highway</td>
<td>60</td>
<td>1.00</td>
</tr>
<tr>
<td>County road</td>
<td>40</td>
<td>1.50</td>
</tr>
<tr>
<td>Land</td>
<td>15</td>
<td>4.00</td>
</tr>
<tr>
<td>Lake</td>
<td>1</td>
<td>60.00</td>
</tr>
<tr>
<td>Main stream of Yangtze River</td>
<td>25</td>
<td>2.40</td>
</tr>
<tr>
<td>Tributary stream of Yangtze River</td>
<td>20</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Note: The land speeds were obtained from the “JTG B01-2003 Technical Standard of Highway Engineering.”
integration value of inland port \( i \); and \( D_{ig} \) is the accessibility between port \( i \) and grid cell \( g \) obtained through the time cost-weighted distance method on ArcGIS 10.1. Table 2 shows the time cost value, that is, the average time required to travel one kilometer. \( \lambda \) is the distance decay parameter measuring the shippers' sensibility to \( D_{ig} \). The value of \( \lambda \) in this paper was designated as two to maintain consistency with common practice (Huff, 1973; Taaffe, 1962).

### 3.3.3 Dividing the development stage of the hinterland

In the case of the MYR port system, the study's underlying assumption is that the current stages of the hinterland economy are correlated with the coordination relationship between port and hinterland, which seems to be a reasonable hypothesis. For example, in the early stage of economic development, a port enjoys a higher probability of handling bulk cargo rather than container cargo, reflecting the port's specialization in raw materials like coal and minerals (Song & van Geenhuizen, 2014). Accordingly, to reduce the computational burden of the estimation of the production and trade, consumer demand, urbanization and demographics, and other characteristics of the hinterland economy, the concept of development stage is introduced in this research.

Research on the economic development stage dates back to the 1950s with some of the most prominent theories of economic development, which can be summarized as four models—the linear stages of growth models, structural change models, international dependence models, and neoclassical counterrevolution models (Dang & Pheng, 2015). However, given the extreme complexity and massive scale of economic development, a set of measurement indices is required that are as few and as simple as possible but that simultaneously contain as much information as possible for the stage division. Chenery, Robinson, and Syrquin (1986) revealed the rich implications of per capita GDP and its significance in dividing economic development stages—largely reflecting a country or region's overall wealth level and measuring the corresponding capital accumulation boundary, thus basically covering the purchasing power and demand structure of an economy. Therefore, this research attempted to reassess Chenery's classification criterion by extrapolating the 1970s' classification to 2001–2013, employing the price deflator of U.S. dollar in 1970 as the conversion factor, and converting U.S. dollars into RMB using the purchasing-power parities (PPPs) to classify the economic development stage of the hinterland. Finally, the economic development was specifically classified into five stages: primary production, primary industrialization, middle industrialization, late industrialization, and the developed economy. Table 3 shows the comparison of specific classification criteria based on U.S. dollars in various years.

### 3.3.4 The coupling coordination degree model

Coupling is a term originating from physical science that refers to the phenomenon whereby two or more systems influence each other through various interactions. The coordination degree is used to describe the level of harmony and compatibility in the development of systems according to the basic principle of synergistic theory. Liao (1999) first combined coupling and coordination degree into the CCDM to evaluate the nonlinear relationships between the elements of two or more systems and factors. Since then, the model has been widely employed in the evaluation of multiple systems in different areas (Ding, Zhao, Huang, Cheng, & Liu, 2015; Song, Zhou, Liu, Siehr, & Qi, 2018; Zhao, Li, & Wu, 2017). The coordinated development of port and hinterland reflects the dynamic process of two systems from disorder to order. Therefore, all related data on port–hinterland in different periods from 2001 to 2013 were collected to analyze the changes in the coupling coordination degree through the trends in the figure of variation.
The special calculation process is as follows:

\[ U_{ct} = \sqrt{\left( F'_{ct} \times V'_{ct} \right) / \left( \left( F'_{ct} + V'_{ct} \right) / 2 \right)^2}, \]  

(8)

where \( U_{ct} \) represents the coupling degree between a port and its hinterland county \( c \) in period \( t \) and the value is between zero to one; \( V'_{ct} \) and \( F'_{ct} \) are the standardized values of \( V_{ct} \) and \( F_{ct} \) obtained by Equations (4) and (7), respectively. However, when the development degree of these two systems is not at the same level, it is difficult for this model to represent the actual level between the two systems. To avoid this, more pertinent indicators were supplemented in the model:

\[ E_{ct} = F'_{ct} / V'_{ct}, \]  

(9)

\[ T_{ct} = \alpha F'_{ct} + \beta V'_{ct}, \]  

(10)

\[ D_{ct} = \sqrt{U_{ct} \times T_{ct}}, \]  

(11)

where \( E_{ct} \) is the relative development degree between a port and its hinterland county \( c \) in period \( t \); \( D_{ct} \) is the coordination degree; \( U_{ct} \) is the coupling degree; and \( T_{ct} \) is the comprehensive coordinating index of inland port and hinterland economic development in the period \( t \). Both \( \alpha \) and \( \beta \) are weights to be determined. For this research, the inland port system is as important as the hinterland system, so the values of \( \alpha \) and \( \beta \) are equivalent: \( \alpha = \beta = 0.5 \).

Combined with previous research (Liao, 1999), the development of coupling of the port–hinterland system was divided into three classes and three subclasses according to the coupling coordination degree \( D \) and the relative development degree \( E \). Subsequently, nine different types were developed based on the comparative relationship between the comprehensive assessment indexes of the inland port system and hinterland system. The specific assessment criteria and grades are shown in Table 4.

### Table 3: Classification criterion of economic development stages by Chenery stage

<table>
<thead>
<tr>
<th>Stage</th>
<th>GDP (dollars per capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary production</td>
<td>140–280</td>
</tr>
<tr>
<td>Primary industrialization</td>
<td>280–560</td>
</tr>
<tr>
<td>Middle industrialization</td>
<td>560–1,120</td>
</tr>
<tr>
<td>Late industrialization</td>
<td>1,120–2,100</td>
</tr>
<tr>
<td>The developed economy</td>
<td>2,100–5,040</td>
</tr>
</tbody>
</table>

Note: The extrapolation employed the price deflator of the U.S. dollar in 1970 as the conversion factor.

4 | SPATIAL EVOLUTION OF THE PORT–HINTERLAND

Considering strong substitutability and more competitive factors (e.g., similar size, parallel service on bulk cargos, and overlapping hinterlands) among inland ports in the MYR, the analysis mainly focuses on the competition aspect without the complex balance between competition and complementarity for port hinterlands. The results of hinterland demarcation and its spatial evolution were
obtained by the following two steps. First, the total field intensity that all eight ports exert on each grid cell was estimated according to the adapted field model. Once obtained, it was interpolated by means of the Kriging process through ArcGIS to draw the maps in Figure 2. Second, county was taken as the analysis unit to calculate the field intensity of each port in the area, and the maximum value was used to decide whether or not the county lies within a given port hinterland.

As seen below, the maps of total field intensity values in Figure 2 show a significant “center–periphery” pattern, which means that regions with higher field intensity values were distributed around the port, while the lower values were widely distributed in peripheral areas without flourishing transportation. It is undeniable that distance has become only one of the factors that could reflect the economic influence of a port on its hinterland. However, it still plays an indispensable role in hinterland configuration, particularly in the context of inland ports. Unlike seaports, the majority of inland ports in MYR deal mainly with bulk cargo, including coal, oil and natural gas, and iron ore, as well as steel. While container operations are concentrated in one or more hub ports, such as Wuhan Port (with container throughput accounting for approximately 50% of the eight ports). It is common that the activities generating bulk cargo or the final consumers are directly linked with the ports, with simpler commodity chains and fewer actors involved. In the early years, there existed little discrepancy among the core influence sphere of the eight major ports. Nevertheless, Wuhan Port gradually reinforced its leadership in the hinterland in the following years and demonstrated overwhelming competitiveness. The region centered on Wuhan Port, Huangshi Port, and Jiujiang Port is expected to become the inland navigation service highland of MYR. In contrast, Yichang Port and Nanchang Port presented a retrograde tendency.

As shown in Figure 2, the definite hinterland borders of eight major inland ports in MYR are difficult to identify. For this reason, a simplified strategy that can quantify the relative scope of the port hinterland is required, both to make comparisons among them and to assess their own evolution.

### TABLE 4  Stages and types of coordination development of port and hinterland economies in the Midstream Yangtze River

<table>
<thead>
<tr>
<th>Stage</th>
<th>D value</th>
<th>E value</th>
<th>Feature of coordination development type</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoordinated stage</td>
<td>0 &lt; D ≤ 0.4</td>
<td>0 &lt; E ≤ 0.8</td>
<td>Seriously uncoordinated development with port service lagged</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 &lt; E ≤ 1.2</td>
<td>Seriously uncoordinated development with port service and hinterland economy</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2 &lt; E</td>
<td>Seriously uncoordinated development with hinterland economy lagged</td>
<td>III</td>
</tr>
<tr>
<td>Transitional stage</td>
<td>0.4 &lt; D ≤ 0.75</td>
<td>0 &lt; E ≤ 0.8</td>
<td>Barely coordinated development with port service lagged</td>
<td>IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 &lt; E ≤ 1.2</td>
<td>Barely coordinated development with port service and hinterland economy</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2 &lt; E</td>
<td>Barely coordinated development with hinterland economy lagged</td>
<td>VI</td>
</tr>
<tr>
<td>Coordinated stage</td>
<td>0.75 &lt; D ≤ 1</td>
<td>0 &lt; E ≤ 0.8</td>
<td>Favorably coordinated development with port service lagged</td>
<td>VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 &lt; E ≤ 1.2</td>
<td>Favorably coordinated development with port service and hinterland economy</td>
<td>VIII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2 &lt; E</td>
<td>Favorably coordinated development with hinterland economy lagged</td>
<td>IX</td>
</tr>
</tbody>
</table>
Comparing the total field intensity of each port in all grid cells within the county is proposed as such a strategy. Moreover, if the value of the given port in a certain county is the maximum, then the county lies within the port's hinterland. The corresponding results are illustrated in Figure 3. Visually, the maps for the hinterland evolution show clear discrepancies between the eight major ports in MYR, although small differences exist in the sphere ranking change from 2001 to 2013. Specifically, Wuhan Port, Changsha Port, and Nanchang Port have maintained dominance status in hinterland development, regarding hinterland size. The total number of counties involved in the hinterland of these three ports occupied approximately 70% in megacity regions in the MYR, while Huangshi Port has been in an unfavorable situation with a minimum area of hinterlands. It is noteworthy that the three ports with the largest hinterland scope are located in the provincial capital cities of Hubei, Hunan, and Jiangxi provinces. In the Chinese context, a regional capital cannot only perform political, economic, and social functions but also possibly provide adequate land transport.

From an inland port point of view, the efficient transport link with different economic centers is a key determinant of port competitiveness. Influenced by the hinterland accessibility that relates to distance, the spatial scope of the corresponding hinterland expanded or shrank around the eight major ports. Considering the significance of hinterland traffic, national or regional involvement in ports often takes the form of investment in port infrastructure or port-related infrastructure, such as hinterland corridors. Wuhan Port, with its Wuning-Ji’an expressway, is an example. Established in 2008, the expressway increases the polarization and zoning of logistics sites in Wuhan Port and along the axes between them and the inland centers. Shippers in Hunan and Jiangxi provinces prefer to transport their containers to Wuhan Port by truck and then ship them to Shanghai due to the cost advantage in so doing. The hinterland development of Wuhan Port confirms the existence of “island” hinterlands in river port systems, as Notteboom and Rodrigue (2005) observed in the major American seaports. Such distant hinterlands are discontinuous in nature due to the structuring effect of transport corridors and logistics nodes, and this is more common in container ports. Moreover, the “island” hinterland of Wuhan Port demonstrates an evident trend of being a continuous hinterland in the future. Simultaneously, the hinterland of Nanchang Port in 2007 appears to be discontinuous. However, through long-term observation, Nanchang Port virtually witnessed a regression in hinterland development that is entirely distinct from Wuhan Port.

To gain a better understanding of the evolutionary tendency of hinterlands, the influence exerted by each port on its hinterland was quantified by the proportion of total field intensity. As indicated in Table 5, the eight ports competed for overlapping hinterland even though inland ports are known to have stronger captive hinterlands than seaports. Specifically, the influence of Wuhan Port enhanced progressively from 48.07% in 2001 to 60.69% in 2013. The benefit from the transport corridor was that it intruded into the natural hinterland of Yueyang Port, Changsha Port, and Nanchang Port along
the Wuning-Ji'an expressway. Fortunately, Yueyang Port ultimately maintained its influence by virtue of the policy advantages of being a national first-class open port and captured the hinterlands of Changsha Port and Jingzhou Port to the west. Accordingly, Jingzhou Port only retained a hinterland with a long strip shape along the north–south national highway No. 207 and the Xiangyang-Jingzhou expressway. The influence of Jiujiang Port was comparable to that of Wuhan Port; thus, expanding the hinterland southward is still the port’s development trend in the future. Notwithstanding the navigation status improved by the Three Gorges Project, the performance of Yichang Port is barely satisfactory in the megacity region of MYR. In this fierce port competition, Huangshi Port has remained at a disadvantage due to the excessive proximity of Wuhan Port, demonstrating a visible decline in influence and shrinking hinterland. As Witte, Wiegmans, and Rodrigue (2017) noted, being proximate to strong neighboring inland ports is not necessarily beneficial to the growth prospects of an inland port.

### 5 | THE COORDINATION RELATIONSHIP IN THE PORT SYSTEM

Based on the definite hinterland borders observed in Section 4, the CCDM is utilized in this section to explore the interplay and coordination development in the river port system since the new millennium. Additionally, the economic development stage has been reconsidered for a better description of the
The changing interaction during the period from 2001 to 2013 and some relative explanations are presented below.

In 2001, the majority of counties within hinterland areas (90.29%) lay at the primary production stage as shown in Figure 4a. This stage is identified by the predominance of primary activities, principally agriculture, as the main source of the increasing output of tradable goods (Chenery et al., 1986). The MYR featured only a few dedicated container handling facilities in 2001, as primary product flows to and from these regions were primarily break-bulk-based. In parallel, almost all the interaction processes between ports and their hinterlands were situated at the transition stage, accounting for 94.86%. Over 70% of counties were characterized as type IV defined in Table 4, which means the whole system reached a status of barely coordinated development with port service lagged. Therefore, the development of major ports in MYR generally lagged behind the hinterland economy, and the pulling effect of ports was limited by the aspects of port handling capacity, water capacity scale structure, and waterway conditions. However, exceptions existed in the county where the port was located, indicating that the location and performance of ports play a significant role in the rise and development of cities during the initial period.

Following completion of the port system deregulation reform in 2002, the port industry in MYR entered a golden period. On the one hand, the rapid economic growth of the hinterland stimulated the demand for port services, particularly after the strategy implementation of central China. On the other hand, China's accession to the WTO in 2001 also greatly prompted more international trade and thus further stimulated rapid growth in Chinese ports (Yang, Chin, & Chen, 2014). As shown in Figure 4b, more than 50% of counties that had been in the primary production stage successfully transitioned to industrialization in 2007. Much of the transport infrastructure in MYR was built during this stage to support the increase in traffic. In particular, Wuhan district and Changsha district took the lead in the regional economy and were the first to enter the stage of late industrialization. This called for the embracing of containerization to fulfill the surge in demand for consumer products. Due to the benefit accrued from the virtues of waterway transport, the promotion of the hinterland economy has thus achieved initial results. These are particularly reflected in the Wuhan Metropolitan Area in which more than 51% of counties moved into the coordinated stage with ports, characterized as type VIII or IX which means the whole system reached a status of favorably coordinated development. The area comprises nine cities: Wuhan, Huangshi, Ezhou, Huanggang, Xiaogan, Xianning, Xiantao, Qianjiang, and Tianmen. Additionally, over 30% of counties developed the interaction process with the port into the stage during which the supply of the port moderately outstripped the demand of the hinterland (i.e., types VI and IX). To some extent, it is an ideal state in the case of rapid economic development.

As shown in Figure 4c, the issue of inefficient port service and unbalanced waterway development was beginning to surface, particularly following the financial crisis that swept the globe in 2008. The crisis not only hit global industry heavily but also hit the trade and port industries through dramatic changes in the demand structure. The growth rate of the cargo throughput of the major ports in MYR slowed markedly, and the backlog of resource products such as iron ore and coal mines was serious. The systematic imbalance contradictory of port service supply and demand in MYR has aggravated since 2008. On the one hand, overheated investment in Wuhan Port for the construction of new terminals or upgrading of handling facilities might have led to considerable overcapacity in the fleet. On the other hand, the hinterland around Changsha Port and Yichang Port entered the late industrialized or developed stages, meaning a major increase in demand for consumer products as well as continued growth of exports. However, the relevant condition and capacity of shipping were unable to satisfy the demand.

In general, with the rapid economic development of megacity regions in MYR and the integration of inland waterway transport in the intermodal supply chain, the contradiction between ports and their corresponding hinterlands evolved and differed from port to port. During the observation period, the
Coordination development between port service and hinterland economy evolved from the transitional stage, characterized by the port lagging behind overall, to the multi-stage, with partial port services outstripping the economic demand of the hinterland. This denotes that the interplay changed from the original port dominance to mutual interaction, influence, and restriction actions, which is in line with Wang (2014).

6 | DISCUSSION AND CONCLUSION

This study presented the spatial–temporal evolution of the port–hinterland relationship with 175 counties or urban prefecture districts in MYR from 2001 to 2013. The analytical framework synthesized the available information on the hinterland of the inland ports. Specifically, it measured two aspects of the hinterland evolution: its geographical scope and the coordination relationship with the inland port. Based on the definite scope of hinterlands, theories and concepts stemming from synergetic and economic development literature—notably on coupling coordination and development stage—were used to explore the interactive relationship between port services and the associated economic development in the hinterland.

The main contribution of this research is that it attempts to add to the existing literature on port systems by studying the coordination between inland ports and the hinterland economy. The case study of port–hinterland development in megacity regions may lead to some interesting suggestions and ideas for inland ports in other parts of China and the world. For instance, it identifies the significance of geographical conditions and transportation facilities in the port–hinterland relationship, which can help different stakeholders make better decisions to meet their respective objectives. For governments, this study can help when evaluating both the impact of port strategies and the influence of factors, such as the improvement of the road/rail infrastructure or the evolution of the economic activity of the port surroundings. Through hinterland analysis, port authorities can better understand the needs of such hinterlands in order to improve port service, as well as the port’s status in the competition with its major rivals to seek cooperation. And for terminal operators, they can identify the potential customers located in the hinterland and negotiate a long-term contract with them. Besides providing useful information in the Chinese context, the study's flexible methodology can be employed in different geographical contexts and on different inland port ranges all over the world, especially in Europe where rivers generally flow through various countries.
Regarding the case study, the empirical analysis conducted allows for the confirmation of the stated hypothesis: it is possible to draw the scope of the hinterland taking only the port evaluation and hinterland accessibility into account through the field model. Despite the fixed port location, the measurement of accessibility by travel time can better mirror how the friction of the distance varies with inland infrastructure improvements, which was previously confirmed for seaport levels (Wiegmans, Van Der Hoest, & Notteboom, 2008). One important characteristic of hinterland evolution is that Wuhan Port has reinforced its leadership with respect to the hinterland among the major ports in MYR and developed an “island” hinterland during the period analyzed, similar to seaports observed by Notteboom and Rodrigue (2005). This implies the necessity of a much quicker integration of the ports with supply chains connected to the regional economy to improve port service. In fact, it is the scale of port cargo transshipment and scope economies, as well as time compression benefits that determine the port’s influence and radiation scope on the hinterland (i.e., the possibility that the hinterland produces port transport demand).

Moreover, the interaction between the port and hinterland economy observed through the CCDM evolves from the transitional stage, with port development lagging behind hinterland development on the whole, to the multi-stage, featuring partial port service outstripping the economic demand of the hinterland. Delving into different development stages of the hinterland economy has led to a nuanced interpretation of the coordination relationship estimated. Taking Changsha Port for instance, although the main hinterlands have completed the industrialization process, the coordination relationship with the port is barely satisfactory. This may be attributed at least partially to the lack of regionally integrated, water channel-based financing and management, similar to Wang and Li’s (2012) observation for the Pearl River Basin. Despite the recent advances made in inland waterway transport to MYR, challenges remain in the form of a disordered market structure, an increasing geographical dispersion of terminal facilities, cargo imbalances, and modal competition from trucking and rail transport. Accordingly, it is essential to develop approaches to enable rapid development in a sustainable manner while maintaining economic growth through the coordination of ports and hinterlands.

The results obtained encourage more in-depth examination into this line of research, and a number of very interesting questions remain for future work. First, the data could be expanded in geographical scope. The methodology proposed in this paper makes it possible to see the extent to which the results of this research can also be applied to different geographical and hydrological/fluvial contexts, particularly other reaches in the Yangtze River. Additionally, while the current research explains how the observed hinterland development occurs, it does not clearly explain why. In this regard, the quantitative analysis of the role played by factors such as port type, economic activities, existence of intermodal terminal, or even the proximity effect is very pertinent and would be of particular interest to both stakeholders and policy makers, who are responsible respectively for the traffic distribution and infrastructure map design under budget restrictions.

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CONFLICTS OF INTEREST

The authors have declared no conflicts of interest for this article.
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REFERENCES


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