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# Assessment and analysis of regional economic collaborative development within an urban agglomeration: Yangtze River Delta as a case study

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## ARTICLE INFO

### Keywords:

Regional collaborative development  
Urbanization  
Industry  
Urban agglomeration  
Yangtze River Delta  
China

## ABSTRACT

Regional collaborative development mainly emphasizes the relationship and degree of connection between cities. Linkages among cities are more complex and diversified in the age of globalization, so that regional economic collaborative development has become even more important than ever. Domestic and foreign competition must be dealt with to enhance the comprehensive strengths of urban agglomeration. This study takes the Yangtze River Delta (YRD) as a representative case to analyze and evaluate the economic synergistic development capacities of the Yangtze River Delta Urban Agglomeration (YRDUA). Location quotients and industrial structure similarity coefficients show that cities with high levels of economic development provide advantages for secondary and tertiary industries, while cities with relatively low economic development levels provide clearer advantages for primary industries. Regarding the movement of the economic barycenter from 2001 to 2016, the overall directional trend was towards the northwest cities. The strength of economic linkages between cities is closely related to distance, population, and levels of economic development. The degree of economic development directly affects the capacity of collaborative development among cities, which then influences the extent of regional collaborative development.

## 1. Introduction

With rapid globalization, urbanization, and regional economic integration, urban agglomeration has become an important aspect of spatial organization and a global issue with an emphasis on cooperation and communication among cities within a region (Luo & Shen, 2008; Wu, 2003, 2007). To a certain extent, globalization has influenced the transformation and elevation in the importance of urban agglomeration (Shen, 2007; Wu & Zhang, 2007). Urban agglomeration is generally regarded as one of the means for a country to manage regionalization (Brenner, 1999, 2004; Lin, 2014), and has become the focus of urban studies (Batten, 1995; Geddes, 1915; Wu, 2017). In particular, due to the uneven development and high environmental cost during economic growth, regional collaborative development within urban agglomeration has become more marked since the 1990s. A large number of theoretical and empirical studies show that regional collaborative development is very important to alleviate the disadvantages of globalization and realize sustainable development (Bruce, 2014; Dabson, 2010; Hirschi, 2010; Kim, Yeung & Choe, 2011; Mukul, 2012; Uyerra,

Sörvik, & Midtkandal, 2014).

Uneven development or social inequality is the geographical manifestation of internal structural contradictions within capital or housing prices in the process of urban development (Hui, Zhong, & Yu, 2016; Smith, 1991). Space is the carrier of various contradictions, and expresses the relationship between them (Massey, 2005). Some scholars have introduced the theory of spatial production and unbalanced development into the study of urbanization and urban issues (Castells, 1977; Harvey, 1982; Lefebvre, 1991; Soja, 1989). They have emphasized the interconnections between time, space, and society, and have discussed the development of global urbanization under the influence of these factors (Arku & Oosterbaan, 2015; Brenner, 2013; Brenner & Schmid, 2015). The interweaving of these factors provides strong support and impetus for rapid urbanization, and also results in multi-scalar separations, involving time-scale separations, space-scale separations, and social separations (Ye, Chen, Chen, & Guo, 2014). Urban agglomerations in China are just the kind of spatial organization that is full of time-space and social contradictions. As one of the three major urban agglomerations in China, the YRD has to follow the pathway of

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<https://doi.org/10.1016/j.habitatint.2018.10.010>

Received 14 May 2018; Received in revised form 15 October 2018; Accepted 31 October 2018

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coordinated development to achieve the goal of building a world-class urban agglomeration, and one of the major tasks of YRD development is to narrow the gap between regions.

The new concept of healthy urbanization or community has gradually emerged as one of the goals of urban development (Chen, Hui, Lang, & Tao, 2016). In 2017, the urbanization rate in China reached 58.52%, and entered a mode of sustainable and steady growth with the new normal economy. The overall urbanization rate of the cities in the YRD is far higher than the national average, and these cities have experienced the process involving spatial production of capital, as well as power and class interaction (Ye, Chen, Duan, & Yang, 2017; Zhang, Li, Hui, & Li, 2016). YRDUA has experienced a significant development boom over the last 30 years (Li & Wu, 2013; Luo & Shen, 2009; Zhang, 2006; Zhang & Wu, 2006; Zhu & Zheng, 2012). At present, YRDUA is facing major challenges, including social conflicts and related issues, large population but lack of resources, and serious environmental pollution, as well as unbalanced and uncoordinated regional development. The spatial development divergence in YRDUA has become very significant, embodied in both the urban-rural areas and between cities. The overall regional planning has mainly focused on the problem of difference and convergence of regional industrial structures. In addition, due to the uneven spatial distribution, the socio-economic development of local cities has reached or exceeded the carrying capacity of the environment and resources, and cities are making efforts to evacuate a part of their functions for overcoming these matters. The urban agglomeration needs to further optimize spatial structure and achieve collaborative development.

Regional collaborative development means that two or more cities break through the boundaries of administrative divisions to make labor, capital, resources, technology and other factors flow freely and form complementary advantages regional competitiveness, in order to achieve the aim of regional common development. Since the reform and opening up, China's economic development has mainly focused on the eastern coastal areas, including the stimulation of coastal cities and the establishment of special economic zones, which further promoted the comparative advantages of the eastern region. With the announcement of "the Belt and Road" initiative and a strategy for Yangtze River Economic Belt (YREB), the development of YRDUA has become a priority issue. The collaborative development of urban agglomeration can produce free flow and optimal allocation of numerous factors, and improve industrial structures and spatial layout. It is also an important way to increase interregional connections and employment opportunities. The YRD was the earliest and most mature urban agglomeration in China (Long, Tang, Li, & Heilig, 2007, 2009), so its collaborative development and optimization of spatial integration are conducive to improving the quality of urbanization and providing a typical developmental model in the country. However, how to integrate the cities' goals, interests, and advantages, rather than function as separate units is already a problem. Rational industrial structures, strong economic ties, comprehensive infrastructure, and sound environmental management, when formed into a unified and ordered structure linked with complementary functions, will provide a critical foundation for achieving sustainable development in YRDUA. A multi-index analysis method to evaluate the collaborative economic development ability within a region is key for understanding cooperative development. This article tries to analyze the development of economic synergy in YRDUA from three aspects: the dominant industrial structures, the movement path of the economic center of gravity, and the strength of economic linkages.

## 2. Methodology

Uneven development reflects the complex linkages between markets, trade, and national or regional policies (Harris, 2008; Krugman, 1981). In the process of rapid urbanization, uneven development has been becoming more serious, which influences regional collaborative

development in China. In order to evaluate the economic collaborative development of YRDUA, this paper selects three evaluation indexes, including the dominant industrial structures represented by location quotients and industrial structure similarity coefficients, the movement path of the economic center of gravity represented by a center of gravity model, and the strength of economic linkages represented by a model of the strength of economic contact.

A location quotient is usually used to judge whether a particular industry can constitute a regionally dominant industry. When the location quotient is greater than 1, it indicates that the industry is a specialized sector in the region and has comparative advantages. Furthermore, the larger the location quotient is, the clearer the advantages and the higher the level of specialization are. When the location quotient is equal to or less than 1, it indicates that the advantages and competitiveness of the industry are weak, and that it is a self-sufficient sector. The location quotient also refers to the ratio of the number of employed persons of a certain industry in a certain city to relate to the number of the employed persons in that industry. The relevant equation used in this study is as follows:

$$LQ_{ij} = \frac{L_{ij}/L_i}{L_j/L}$$

where  $LQ_{ij}$  is a location quotient for  $j$  industry of  $i$  city ( $j = 1, 2, 3$ );  $L_{ij}$  is the number of employed persons of  $j$  industry in  $i$  city;  $L_i$  is the total number of employed persons in  $i$  city;  $L_j$  is the number of employed persons of  $j$  industry in the study area; and  $L$  is the number of employed persons in the study area.

The degree of industrial structure convergence refers to the similar tendencies that appear in the development of industrial structures in different regions with common characteristics, or the highly similar emerged and intensified trends. This study uses the industrial structure similarity coefficient to assess the similarities of the three industrial structures in three provinces and one city in YRDUA. When  $\rho = 1$ , the industrial structure of the two regions is exactly same; when  $\rho = 0$ , the industrial structure of the two regions is completely inconsistent. The relevant equation is below:

$$\rho = \frac{\sum_{k=1}^n x_{ik}x_{jk}}{\sqrt{\sum_{k=1}^n x_{ik}^2 \sum_{k=1}^n x_{jk}^2}}$$

where  $\rho$  is the similarity coefficient of industrial structure in two regions;  $X_{ik}$  and  $X_{jk}$  are the proportions of  $k$  industry in  $i$  and  $j$  regions, respectively ( $k = 1, 2, 3$ ).

As an important term in physics, the evolution of a gravity center over time can reflect the spatial evolution of certain properties. The evolution of the economic center of gravity depends on spatial distribution and adjustment of economic activities in a certain region. This study uses a gravity center model to analyze the movement path of the economic center of gravity of YRDUA from 2001 to 2016 based on GIS (Geographic Information System). The relevant equation is below:

$$\begin{aligned} \text{Longitude coordinates } X_t &= \frac{\sum_{i=1}^m x_i g_i}{\sum_{i=1}^m g_i} & \text{Latitude coordinates } Y_t \\ &= \frac{\sum_{i=1}^m y_i g_i}{\sum_{i=1}^m g_i} \end{aligned}$$

where  $X_t$  and  $Y_t$  are the longitude coordinates and latitude coordinates of the economic center of gravity of year  $t$ , respectively;  $g_i$  is the regional GDP of the city;  $x_i$  and  $y_i$  are the longitude coordinates and latitude coordinates of the city, respectively.

The degree and direction of economic linkages between cities in a region often determine the economic development of the entire region. In this study, a model of economic contact strength based on spatial interaction theory, is used to measure the extent of urban connections in YRDUA, and clarify the economic linkages between all the other cities of YRDUA and five central cities of Shanghai, Nanjing, Suzhou,

Hangzhou, and Hefei. The relevant formula is as follows:

$$R_{ij} = \frac{\sqrt{P_i G_i} \times \sqrt{P_j G_j}}{D_{ij}^2}$$

where  $R_{ij}$  is the strength of spatial economic linkage between  $i$  city and  $j$  city;  $P_i$  and  $P_j$  are resident populations of two cities;  $G_i$  and  $G_j$  are regional GDPs of two cities; and  $D_{ij}$  is the highway mileage between two cities.

The data for this study has been obtained mainly from Anhui Statistical Yearbook, Jiangsu Statistical Yearbook, Shanghai Statistical Yearbook, Zhejiang Statistical Yearbook, and China City Statistical Yearbook (SBA, 2017; SBJ, 2017; SBS, 2017; SBZ, 2017; NBSC, 2017a; 2017b), which are generally effective and reliable, especially for the analysis of the large-scale temporal and spatial scale within YRDUA from 2001 to 2016.

### 3. Analysis of cooperative development within YRDUA

#### 3.1. The development and evolution of YRDUA

YRDUA has experienced a process of “expanding rapidly, abruptly shrinking and steadily expanding” in recent decades, and several major regions have been formed in this process, such as Suzhou-Wuxi-Changzhou region, and Hangzhou Bay. These metropolitan zones have implemented an urbanization strategy, which has further enhanced overall competitiveness of YRDUA.

According to the “Yangtze River Delta Urban Agglomeration Development Plan” released by the National Development and Reform Commission in June 2016, YRD consists of 26 cities, including Shanghai; Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yangzhou, Zhenjiang, and Taizhou in Jiangsu province; Hangzhou, Ningbo, Shaoxing, Huzhou, Jiaxing, Jinhua, Zhoushan, and Taizhou in Zhejiang province; and Hefei, Wuhu, Ma'anshan, Tongling, Anqing,

Xuancheng, Chizhou, and Chuzhou in Anhui province. This paper focuses on this area and its cities (Fig. 1).

YRDUA, noted for its flat terrain, advantageous climate and rich nature resources, has become one of the regions with the highest level of urbanization and the most developed economy in China. From 2001 to 2016, the total GDP of YRDUA showed a rapid upward trend (Fig. 2), with a growth rate from 2003 to 2004 of 20.37% being the highest for the period. However, due to the global economic crisis in 2008, the growth rate from 2008 to 2009 reached its lowest point at only 9.3%. In recent years, following the requirements of the new normal economy and with an emphasis on the economy of “stabilizing structural growth” based on sustainable development, the growth rate of the GDP in YRDUA has decreased, particularly since 2012, to achieve new urbanization goals in respect of urban and rural planning, environmental protection, and balanced development. Considered at the provincial and municipal levels in 2016, the 9 cities in Jiangsu province had the highest GDP, followed by the 8 cities in Zhejiang province, but the total output value of Shanghai was far higher than that of the 8 cities in Anhui province. A substantial GDP gap between Anhui, Jiangsu, Zhejiang, and Shanghai is evident, which is one of the reasons why Anhui was very keen to join YRDUA, through regional cooperation and industry transfer, to promote economic growth.

In 2016, the 26 cities in YRDUA accounted for 2.21% of national total land area and 10.97% of total residential population, and created 19.88% of the GDP (Table 1). Compared with the 2.26% of land area, 8.1% of residential population, and 10.16% of GDP in the Beijing-Tianjin-Hebei region, the overall economic development capacity of YRDUA is stronger. In particular, with the promotion of YREB as part of the national developmental strategy and “the Belt and Road” initiative, the status of YRDUA has risen to new heights.

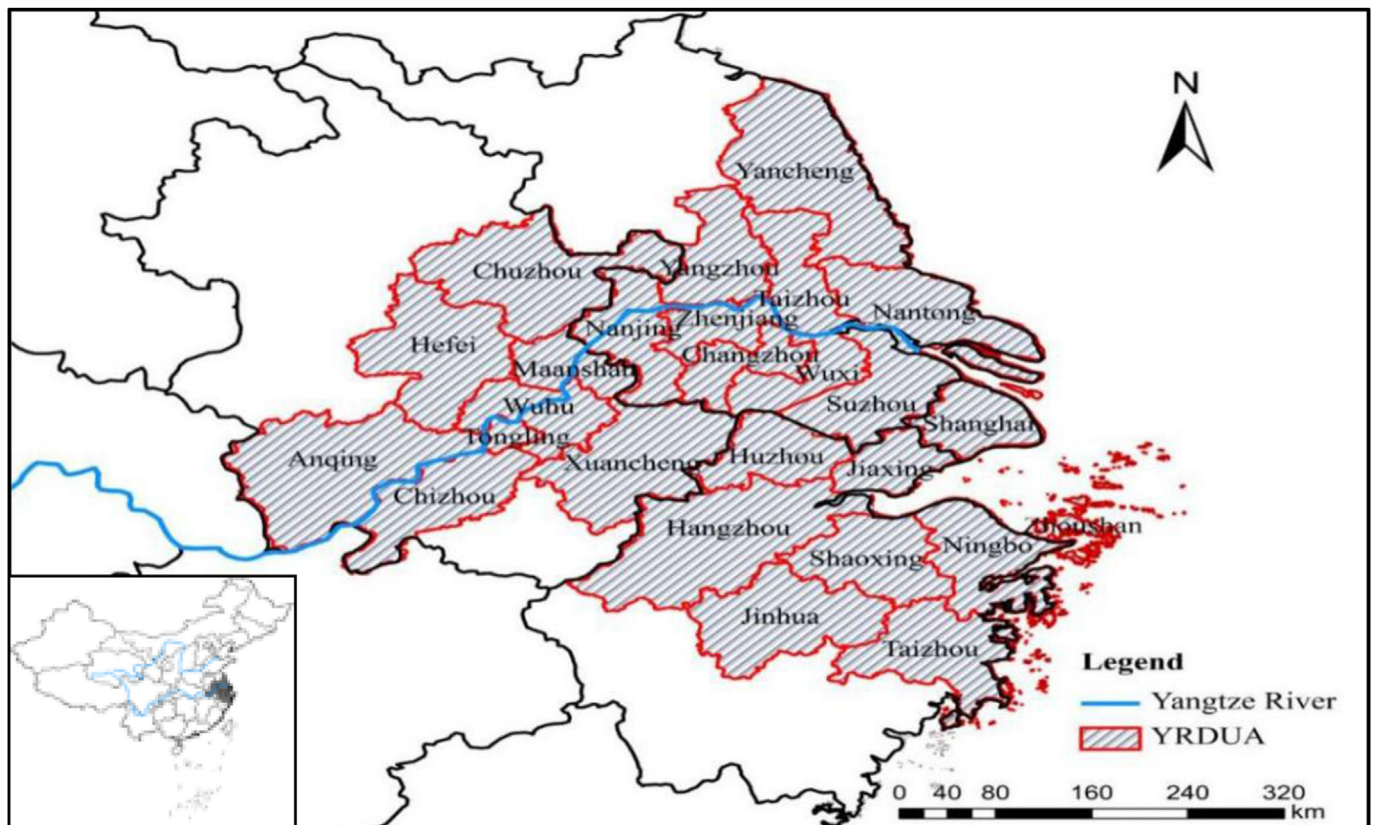


Fig. 1. Geographic location of the YRDUA in China.

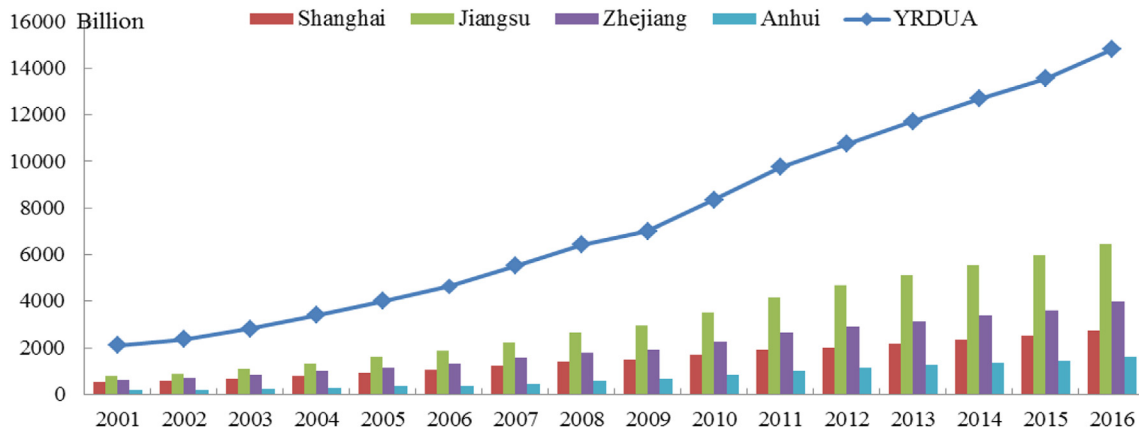


Fig. 2. Evolution of GDP in the YRDUA

3.2. Analysis of the development of economic linkages in YRDUA

The economic linkage of a region can be considered from the inner force and the collaborative force. In general, the inner force can be represented by the dominant industrial structures and the movement path of the economic center of gravity, and the collaborative force can be represented by the strength of economic linkages. The vigorous industrial structures can drive the relevant industries and provide internal economic impetus for regional development. Moreover, the movement of the economic center of gravity itself is an economic activity phenomenon. Its movement path is closely related to government policies and the city's economic development strength, which will attract investors and provide an inner force for the regional economic development. The strength of economic linkages between cities reflects the ability of achieving regional economic collaborative development. If the economic linkages are strong, it indicates the region's great synergy and strong capacity for economic collaborative development, and vice versa.

Regional economic collaborative development mainly depends on collaborating industrial of the cities within the region. The industrial synergy of the cities in YRD is higher than other regions. As the largest financial center in China, Shanghai can provide capital for other cities; the higher education in Nanjing is very developed; Suzhou is the national high and new technology industry center so that it can provide high-tech support; Hangzhou is the global Internet network information center; and Zhoushan port in Ningbo can provide a smooth flow of people, logistics, capital, and information. Resources are shared among these cities to realize rational allocation and effective use. For example, there were short-term movements of technicians and engineers from Shanghai to some cities in Jiangsu in the weekend early in the 1980s, which is called "weekend engineers". The cities like Suzhou, Hangzhou and Ningbo which are adjacent to Shanghai, have developed service or information industries. Nanjing, Jiaxing, Shaoxing, Changzhou, Nantong and Zhenjiang based on their own industrial foundation, focus on the electronic, petrochemical and machinery manufacturing

industries. Some other cities with low-level industrial base mainly develop the transferred industries from above developed cities (Xu, 2014). For instance, Shanghai is an important automobile industry center in China, thus the cities around Shanghai like Jiaxing, Ningbo, Changzhou and Hefei has shifted to parts sectors of automobile production. Through regional strategic cooperation, the regional automobile industrial chain comes into being.

Upgrading industrial structure is inevitable for further improved regional industrialization. The high-tech industries are often regarded as the main direction, and manufacturing as the basic and support. Taking the four years of 2001, 2006, 2011, and 2016 as breakpoints, the three industrial location quotients in relation to primary, secondary, and tertiary industries within the 26 cities of YRD were measured. The cities with relatively high levels of economic development, secondary and tertiary industries constituted advantageous industries, and the advantages of tertiary industry became increasingly obvious with high-level specialization. While some cities with relatively low-level economic development, such as cities of Anhui and Zhejiang, had advantages in primary industry, most of their secondary and tertiary industry location quotients were below 1. Over the four selected years, the cities where primary industry always had comparative advantages included Yancheng, Taizhou, Jinhua, Hefei, Wuhu, Ma'anshan, Anqing, Xuancheng, Chizhou, and Chuzhou. Among them, Chizhou had the largest number of advantages. In 2001, the location quotient was 1.60, and in 2016 it was 2.75. Cities where secondary industry always had comparative advantages included Wuxi, Changzhou, Suzhou, Zhenjiang, Ningbo, Shaoxing, Huzhou, and Jiaxing. Among them, Suzhou had the greatest number of advantages, with a location quotient of 1.40 in 2001 and 1.42 in 2016. Tertiary industry always had comparative advantages in Shanghai, Nanjing, Hangzhou, Zhoushan, and Wuhu, among which Shanghai had the largest number of advantages; in 2001, its location quotient was 1.56, and in 2016 it was 1.43.

The industrial structure of each city has undergone certain changes (Fig. 3). Shanghai and South Jiangsu have generated a pattern whereby secondary and tertiary industries jointly support economic growth, and

Table 1  
Regional overview in the YRDUA (2016).  
(Source: NBSC, 2017b).

	Land area		Total population		GDP	
	Area/km <sup>2</sup>	National proportion	Population/million	National proportion	GDP/billion	National proportion
YRDUA	212953.3	2.21	151.72	10.97	14794.36	19.88
Shanghai	6340.5	0.06	24.20	1.75	2746.61	3.69
Jiangsu	67942	0.71	57.01	4.12	6469.13	8.69
Zhejiang	66543	0.69	42.40	3.07	3976.01	5.34
Anhui	72127.8	0.75	28.12	2.03	1602.57	2.15



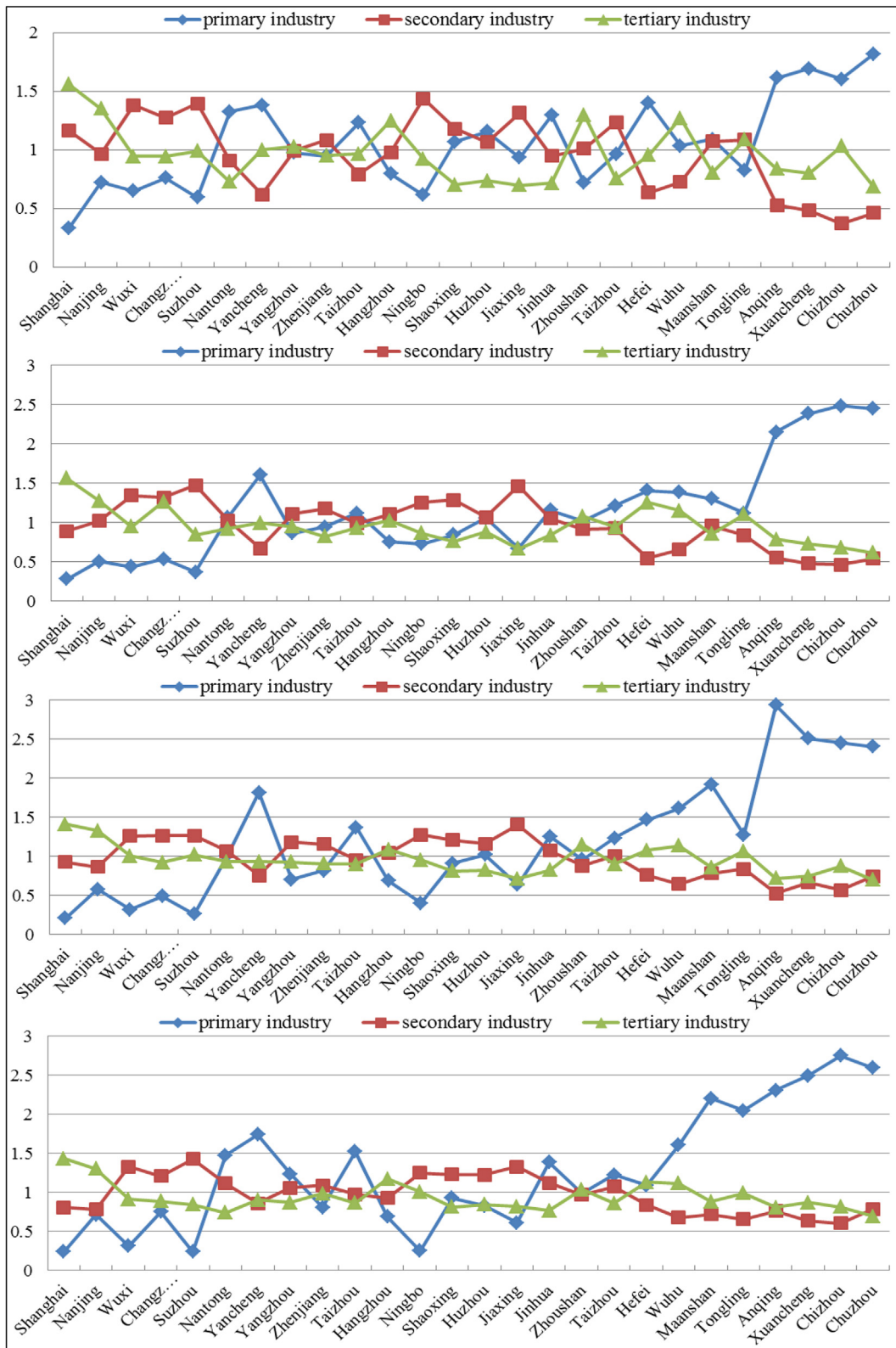


Fig. 3. Evolution of the location quotient of the three industries in the YRDUA (2001, 2006, 2011 and 2016).

at the same time have gradually accelerated the development of tertiary industry, whereas primary and secondary industries in Zhejiang and Anhui account for a relatively large proportion. Zhejiang and Anhui are actively carrying out upgrading their industrial structure and moving towards a secondary and tertiary industries-led economic transformation. The industrial development pathways of cities have their own

characteristics, and there are some differences in the degree of specialization. Concerning the degree of industrial structure convergence, the industrial structures of the 26 cities in YRD from 2001 to 2016 exhibited an overall trend (Fig. 4): the proportion of primary industry continuously declined, while the proportion of tertiary industry increased. Among the cities, Shanghai had the lowest proportion of

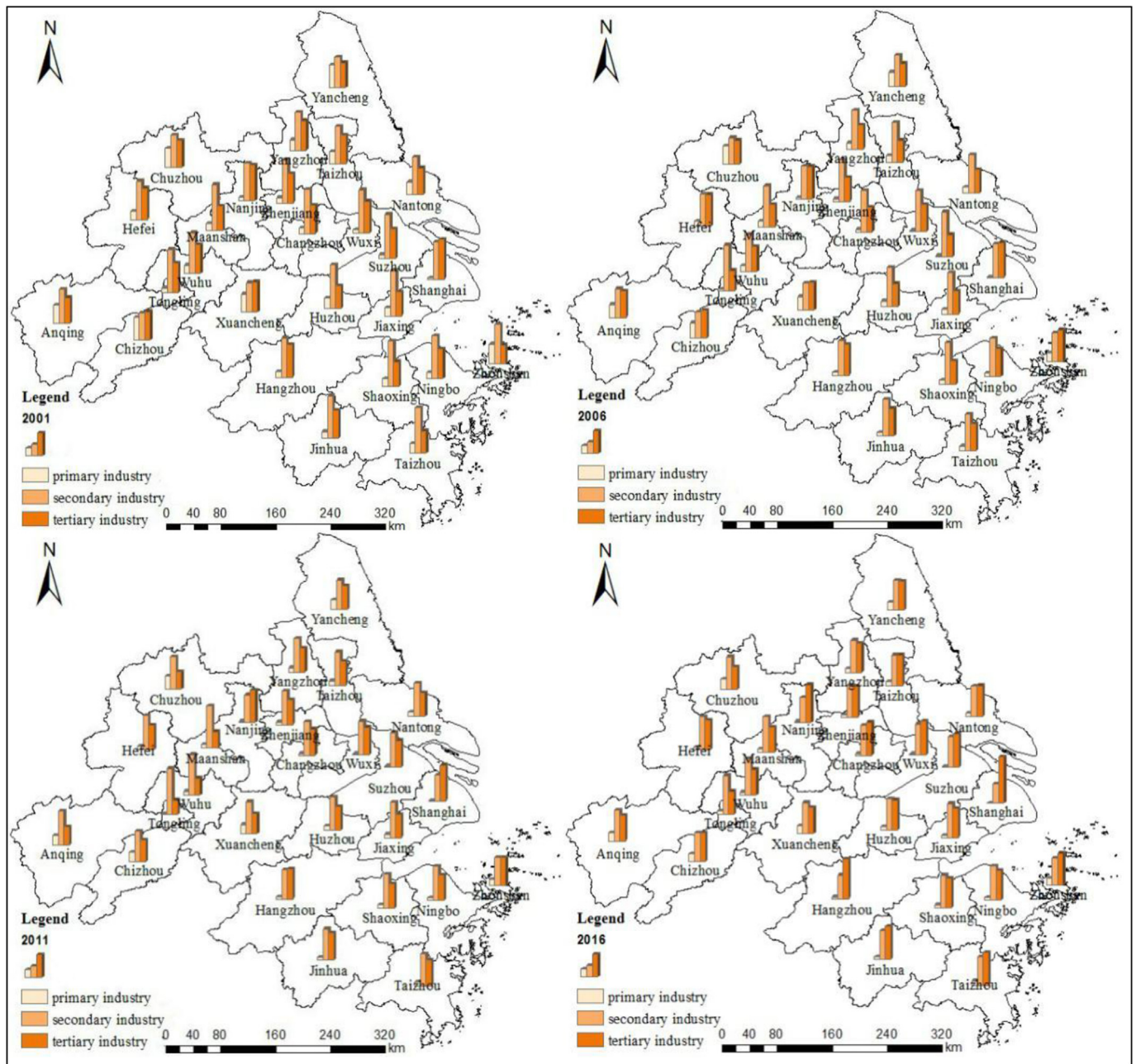


Fig. 4. Evolution of the primary, secondary and tertiary industrial structures in the YRUA.

**Table 2**  
Similarity coefficient of industrial structure in the YRUA.  
(Source: NBSC, 2002, 2007, 2012, 2017).

Area	Similarity coefficient of industrial structure			
	2001	2006	2011	2016
Shanghai-Jiangsu	0.9777	0.9691	0.9628	0.9404
Shanghai-Zhejiang	0.9684	0.9817	0.9632	0.9432
Shanghai-Anhui	0.9427	0.9755	0.8936	0.8701
Jiangsu-Zhejiang	0.9989	0.9978	0.9999	0.9999
Jiangsu-Anhui	0.9834	0.9861	0.9812	0.9854
Zhejiang-Anhui	0.9820	0.9928	0.9813	0.9843

primary industry and the highest proportion of tertiary industry. In 2001, the ratio of primary, secondary, and tertiary industries in Shanghai was 1.73:47.58:50.69 and 0.40:29.11:70.49 in 2016. In

particular, the increase in the proportion of tertiary industry indicates that the adjustment of industrial structure has achieved significant results in Shanghai. The proportion of primary industry in Anhui province was generally relatively high, and the proportion of tertiary industry relatively low. However, changes have taken place in the industrial structure of Anhui in recent years with the declining proportion of primary industry and the increasing proportion of secondary and tertiary industries. The industrial structures of Jiangsu and Zhejiang provinces were similar. In terms of cities, secondary and tertiary industries in Nanjing, Wuxi, Changzhou, Suzhou, Zhenjiang, Hangzhou, Ningbo, and Shaoxing accounted for a large proportion, while Nantong, Yancheng, and Zhoushan had a relatively large proportion of primary industry.

The three industrial structure similarity coefficients of the three provinces and Shanghai in YRD showed a downward trend, but the change was not significant (Table 2). The industrial structure similarity between Shanghai and Jiangsu was as high as 0.98 in 2001 and

**Table 3**  
The top ten cities in economical relation intensity with Shanghai.  
(Source: SBA, SBJ, SBS, SBZ, 2002, 2007, 2012, 2017).

Ranking	2001	2006	2011	2016	Growth rate in 2006 compared to 2001	Growth rate in 2011 compared to 2006	Growth rate in 2016 compared to 2011
1	Suzhou	279.68	793.46	2005.89	2945.14	Suzhou	Hefei
2	Nantong	138.94	315.86	717.75	1123.65	Tongling	Hefei
3	Jiaxing	131.84	309.48	754.33	1110.35	Hefei	Nanjing
4	Wuxi	131.16	281.62	774.84	1096.90	Ma'anshan	Chuzhou
5	Hangzhou	91.11	218.10	530.64	838.97	Nanjing	Yangzhou
6	Ningbo	49.69	117.26	295.48	436.56	Changzhou	Taizhou
7	Changzhou	44.22	112.58	264.40	410.29	Zhoushan	Hangzhou
8	Huzhou	39.69	88.84	198.05	298.69	Hangzhou	Zhenjiang
9	Shaoxing	38.92	87.46	195.17	285.71	Ningbo	Wuhu
10	Nanjing	26.50	69.87	164.31	263.44	Wuhu	Nantong

decreased to 0.94 in 2016. The similarity coefficient with Zhejiang and Anhui also declined, with that of Anhui declining more rapidly and reaching 0.87 in 2016. The three industrial structures in Jiangsu and Zhejiang had the highest similarity, almost being 1 in 2001 and 2016 because of the similar developmental context and levels, with the same level industrial structure. Due to a lack of cooperation and planning in the process of adjusting their industrial structures, which has resulted in a new round of industrial convergence, the similarity coefficient between Jiangsu and Anhui, and between Zhejiang and Anhui, changed little from 2001 to 2016, remaining around 0.98, and increasing again in 2016 after a slight decline around 2011 (see Table 3).

The economic center of gravity of YRDUA from 2001 to 2016 remained within the territory of Suzhou, roughly at latitude 31°2'59"N to 31°10'22"N and longitude 120°8'27"E to 120°20'33"E in the east of the urban agglomeration, which further reflected the differences in regional economic development (Fig. 5). The economic contributions of Shanghai and Suzhou accounted for more than 20%, indicating that the developed cities played a strong role. From 2001 to 2003, the economic center of gravity moved southeastwards; from 2003 to 2005, it moved northwestwards; from 2005 to 2006, it moved southeastwards; from 2006 to 2015, it moved northwestwards; and from 2015 to 2016, it moved to the southwest. Among these changes, the largest extent of movement occurred from 2004 to 2005 with a 6.14 km movement to the northwest, and the smallest movement occurred from 2015 to 2016 with a 0.29 km movement to the southwest. The overall direction of movement was broadly to the northwest, indicating that policy

guidance for encouraging the reduction of development gaps between cities, coupled with the leading role of the central cities, enabled the economic center of gravity of YRDUA to gradually move westwards, and city gaps gradually narrowed. According to the movement trajectory over 15 years, the economic center of gravity of YRDUA would probably continue to move westwards (see Fig. 6).

It is apparent that the closer a city is to a central city, the stronger will be its own economic development, the greater will be the intensity of economic contact with the central city, and the more concentrated will be the spatial distribution (Tab. 3). Shanghai has an extensive geographical radiation effect and is closely linked with surrounding cities, especially Suzhou, Nantong, Jiaxing, Wuxi, and Hangzhou. Among these cities, the distance between Suzhou, Jiaxing and Shanghai is approximately the same, but because of Suzhou's high level of economic development and large population, the strength of economic relationship between Shanghai and Suzhou in 2016 was as high as 2945.14, which was far greater than the economic ties with Jiaxing. Hefei, Nanjing, Hangzhou, and Wuhu ranked the top four in terms of growth rates in 2006 compared to 2001, in 2011 compared to 2006 and in 2016 compared to 2011. This shows that Shanghai's radiation capabilities have continued to increase and it has become increasingly connected to cities. From 2001 to 2011, the intensity of economic ties between Shanghai and other neighboring cities grew rapidly during the decade with an average growth rate of 135.43%, compared to an average growth rate of 55.16% between 2011 and 2016.

Nanjing had close economic ties with Ma'anshan, Zhenjiang,

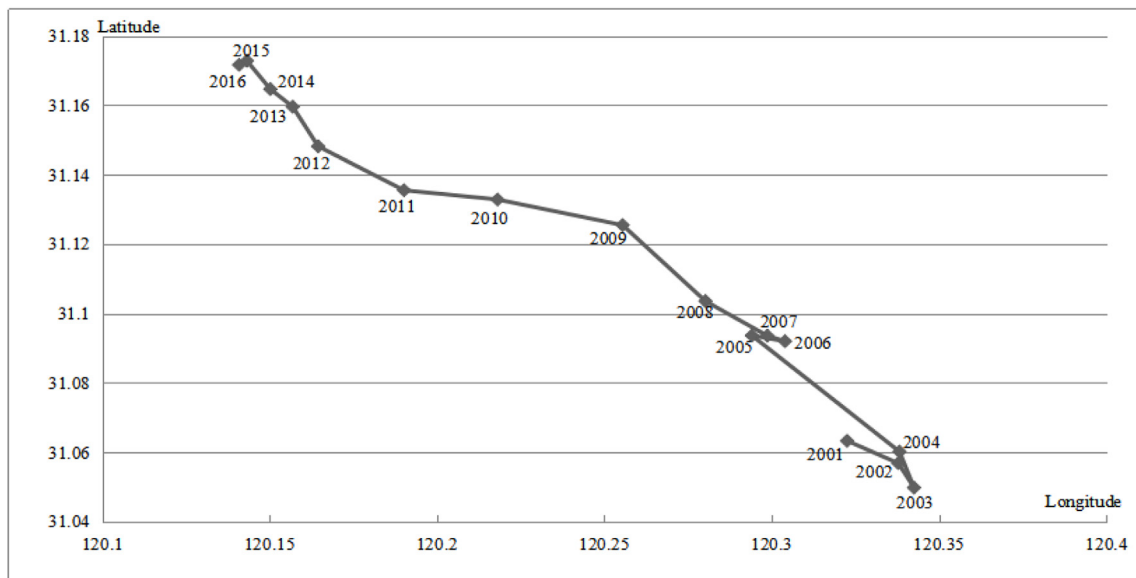


Fig. 5. Directional trend of the economic barycenter in the YRDUA.



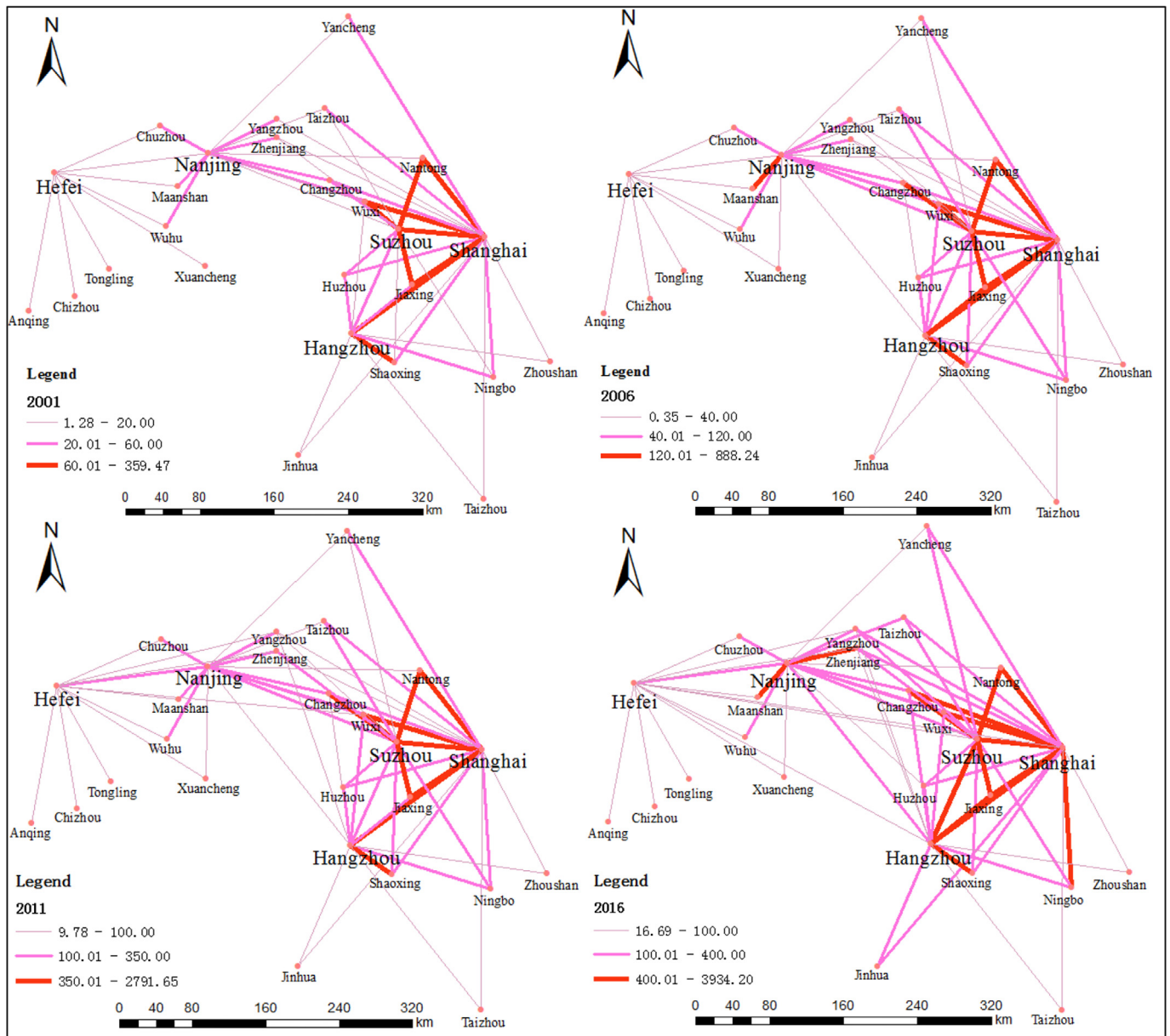


Fig. 6. Evolution of spatial economic contact intensity in the YRDUA.

Yangzhou, and Chuzhou, and these cities ranked among the top four in relation to the strength of economic ties with Nanjing. As the neighboring city of Anhui and South Jiangsu, Nanjing had been the focus of most external connections beyond the YRD, while Shanghai was powerful economically with an extensive radiation radius, the strength of economic ties between Shanghai and Nanjing ranked sixth due to the relatively long distance. The city with the highest growth rate in 2006 compared with 2001 was Suzhou (203.45%). Hefei (199.81%) had the highest annual growth rate in 2011 compared with 2006, and Tongling (151.08%) had the highest growth rate in 2016 compared with 2011. Although Suzhou is not a provincial capital city, its economic development level was the second in YRDUA and it has strong economic ties with cities such as Wuxi, Shanghai, Jiaxing, Nantong and Changzhou. The intensity of the connection between Suzhou and Anhui steadily increased. Tongling (222.62%), Hefei (210.14%), Ma'anshan (208.14%), and Wuhu (170.49%) were among the top 10 cities in terms of growth rate in 2006 compared to 2001, while Hefei (222.31%), Wuhu (182.83%) and Chizhou (172.80%) were among the top 10 cities in terms of growth rate in 2011 compared to 2006. Finally, Tongling

(129.93%), Hefei (62.44%), Chuzhou (58.60%), Wuhu (56.48%) were among the top 10 cities in terms of growth rate in 2016 compared to 2011, with relatively high rankings.

Hangzhou had strong economic ties with Shaoxing, Jiaxing, Huzhou and Ningbo in Zhejiang, as well as with two central cities, Shanghai and Suzhou. Shaoxing was the city having the strongest economic ties with Hangzhou, with 143.90 in 2001 and 1209.01 in 2016, while the city of having the weakest economic ties with Hangzhou was Chizhou, with 0.54 in 2001 and only 5.59 in 2016. The top three cities in terms of growth rate in 2006 compared to 2001 were Suzhou (175.49%), Tongling (172.21%), and Hefei (161.68%). The top three cities in 2011 compared to 2006 were Hefei (210.19%), Wuxi (202.47%) and Suzhou (177.91%). The top three cities in 2016 compared with 2011 were Tongling (147.59%), Hefei (74.92%) and Nanjing (71.87%). These results showed that the economic ties between Hangzhou and cities in Jiangsu and Anhui had increased rapidly.

As the capital of Anhui province, Hefei had a relatively low economic development level compared with Shanghai, Nanjing, Suzhou, and Hangzhou. Therefore, overall, the economic linkages between



Hefei and other cities were far less than those of the four central cities. Hefei only had frequent economic exchanges with cities such as Nanjing, Wuhu, Chuzhou, and Anqing, and the highest level of connection was between Hefei and Nanjing, which was 193.43 in 2016, while the lowest was between Hefei and Zhoushan, which was 1.88 in 2016. Hefei ranked among the top 3 cities, because of the accelerated economic exchanges and factor flows with other cities in YRD over a fifteen-year period.

#### 4. Discussions and conclusions

Regional collaborative development is very important in regional studies. The collaborative development ability of a city or region is based on economic development level and connections with other regions, which directly determines the degree of collaborative development within a region. Based on the Yangtze River Delta Urban Agglomeration Development Plan issued in 2016, this study selected 26 cities of YRDUA and analyzed the evolving characteristics of the urban economic linkages within the urban agglomeration from 2001 to 2016.

In terms of the collaborative development capacity of YRDUA, the conclusions can be drawn as following. Considering an advantageous industrial structure, the location quotients and the industrial structure similarity coefficients showed that secondary and tertiary industries were highly successful industries in the cities with relatively high levels of economic development, with the advantages of tertiary industry becoming increasingly evident. Cities with relatively low levels of economic development, such as some cities in Anhui and Zhejiang, had obvious advantages in primary industry, with all the secondary and tertiary industry location quotients below 1, indicating that the advantages and competitiveness of the industries in these cities were weak. However, from 2001 to 2016, the proportion of primary industry in each city has continuously declined, the proportion of tertiary industry has shown fluctuating upward, and the similarity coefficients of the three industrial structures has also declined; however, the changes are not significant. Judging from the trajectory of the economic center of gravity, although the economic center of gravity of YRDUA remained in Suzhou city from 2001 to 2016, it has been moving steadily in a northwest direction overall, which probably implies the future trend of the westward economic barycenter, while the developmental gap in the region narrowed between 2001 and 2016. Considering the intensity of economic ties, the intensity of economic contact between cities was closely related to distance, population size, and economic development levels. The closer a city was to a central city, and the greater its level of economic development and population size, the greater the economic ties with the central city would be. Finally, the extent of economic development directly affected a city's capacity for collaborative development, which is likely to further affect the regional cooperative development capacity of YRDUA.

Regional collaborative development in YRDUA is concerned about many different scales. YRD has achieved a remarkable degree of development to become the most economically developed region with the highest level of urbanization in China, due to its advantageous geographical location and supportive official policies. However, uneven geographical development and an unbalanced spatial distribution of various resource factors has also led to many challenges in respect of collaborative development. Unbalanced regional development, severe industrial structure convergence, and a lack of regional cooperative organizations, which detrimentally affect the collaborative development of YRDUA. Therefore, spatial integration and reconstruction in YRD is critical to achieve the goals of complementarity and mutually beneficial cooperation between cities, and the construction of a world-class urban agglomeration. Given the spatial patterns of the YRD, the main focus for future spatial integration needs to be on the surrounding towns and the metropolitan areas developing in conjunction with the central cities to facilitate the construction of a modern integrated industrial system.

The collaborative development of urban agglomerations needs more comparative research in the future. The experiences of regional collaborative development in YRDUA could be helpful to the other urban agglomerations. In particular, Beijing-Tianjin-Hebei (BTH) and the Pearl River Delta (PRD), to some extent, have the same developmental status and trends as YRD. However, the three urban agglomerations have different geographical locations, policies and challenges. The collaborative effect of BTH is not enough, and regional industrial isomorphism is serious. PRD lacks economic growth aftereffects, and its inherent advantages from reform and opening up have been greatly weakened. The collaborative development of YRD and PRD is mainly driven by market, but BTH is greatly influenced by the administrative power because of Beijing as the capital. The imbalance of administrative power and the unequal political and economic status of Beijing, Tianjin and Hebei have seriously affected the cooperation and collaborative development of the region. To balance the relation between administrative power and market forces is pivotal for regional collaborative development.

As a hot topic in human geography or social sciences, regional collaborative development needs multidisciplinary perspectives and multi-scalar methods. Regional collaborative development can also be analyzed from the perspectives of infrastructure, ecology and environment sciences. For the developing countries like China, it is urgent to achieve the aim of collaborative development of economic, society, environment and infrastructure. It is worth exploring how to evaluate the collaborative development ability of regional infrastructure and ecological environments. Therefore, it is necessary to conduct some comparative researches based on some typical cases and methodological examination on how to use and integrate the different methods.

#### Acknowledgements

This work is supported jointly by Peak Discipline Construction Project of Education at East China Normal University and National Natural Science Foundation of China (Grant No. 41571138, 41671125, 41471135, 41771171), and “Dawn” Program of Shanghai Education Commission (17SG27). The insightful and constructive comments from the editors and reviewers are appreciated.

#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.habitatint.2018.10.010>.

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