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Industrial Green Spatial Pattern Evolution of Yangtze River Economic Belt in China

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Abstract: We use the directional slacks-based measure of efficiency and inverse distance weighting method to analyze the spatial pattern evolution of the industrial green total factor productivity of 108 cities in the Yangtze River Economic Belt in 2003–2013. Results show that both the subprime mortgage crisis and 'the new normal' had significant negative effects on productivity growth, leading to the different spatial patterns between 2003–2008 and 2009–2013. Before 2008, green poles had gathered around some capital cities and formed a tripartite pattern, which was a typical core-periphery pattern. Due to a combination of the polarization and the diffusion effects, capital cities became the growth poles and 'core' regions, while surrounding areas became the 'periphery'. This was mainly caused by the innate advantage of capital cities and 'the rise of central China' strategy. After 2008, the tripartite pattern changed to a multi-poles pattern where green poles continuously and densely spread in the midstream and downstream areas. This is due to the regional difference in the leading effect of green poles. The leading effect of green poles in midstream and downstream areas has changed from polarization to diffusion, while the polarization effect still leads in the upstream area.

Keywords: Yangtze River Economic Belt; industrial green total factor productivity; directional slacks-based measure of efficiency; inverse distance weighting; spatial pattern evolution

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1 Introduction

The Yangtze River is the third longest river in the world, and the longest river in Asia, flowing through 11 provinces in eastern, central, and western China. According to 'Guidelines on relying on the golden waterway to stimulate the development of Yangtze River Economic Belt', issued by the State Council of China, the Yangtze River Economic Belt has become an official national strategy. Its land area is about 2.05×10^6 km^2, which covers over 20% of China's land area, and its population and GDP account for over 40% of China's population and GDP. Moreover, the share of the gross industrial output value of the Yangtze River Economic Belt has been above 40% for a decade, and even higher than 41% in the last three years with less than 34% of China's industrial pollutant emissions. Undoubtedly, developing the Yangtze River Economic Belt is of great significance in building a horizontal economic belt and forming China's new growth pole. Against the background of the 'new normal', China's development is undergoing a period of strategic importance, highlighting the opportunity of a green economy and environmental protection. The industrial green development of the Yangtze River Economic Belt is also undergoing a similar transition, thereby emphasizing the practical significance of related research.

Green total factor productivity (GTFP) is a common index that reflects green development. The methods of measuring GTFP have developed over decades. In the

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beginning, pollutant emission was considered an input in the production function to measure GTFP, but this was not economically intuitive because its significant characteristics are those of an output. Accordingly, it was then considered an output in the Shepard distance function but its negative externality was not considered (Färe *et al*., 1994). This method was inadequate as well, as not accounting or incorrectly, accounting for environmental factors could mislead results (Marthin *et al*., 2007). When activity analysis models were based on the directional distance function, and treated pollutant emission as an undesirable output (Chambers *et al*., 1996; Chung *et al*., 1997), the effect of environmental factors on TFP could be measured reasonably for the first time. Later, a directional slacks-based measure (SBM) of efficiency and the Malmquist-Luenberger (ML) index were used (Tone, 2001; Fukuyama and Weber, 2009; Färe and Grosskopf, 2010).

Many scholars measured China's industrial GTFP, but only a few studies focused on the Yangtze River Economic Belt. Some scholars used the industrial sectors' data (Jefferson *et al*., 2000; Chen *et al*., 2011), industrial enterprises' data (Chen *et al*., 1988) and manufacturing data (Szirmai and Wang, 2008) to measure China's industrial development and estimate China's industrial productivity (Chow, 2008; Young, 2003; Li, 2009; Chen *et al*., 2009). As a study showed, the annual rise of China's industrial GTFP was 2.29% (Chen, 2010) during 1980–2008, which was significantly lower than traditional TFP without considering environmental factors (Zhang *et al*., 2011; Chen and Golley, 2014). Technological change is the main driver of GTFP growth (Du *et al*., 2017) and the high-tech industry contributed significantly to China's industrial GTFP growth, while a few heavy chemical industries were still in the period of extensive growth that relied on resource input, which slowed down the growth of industrial GTFP (Chen, 2009). There is a huge regional difference of industrial GTFP in China (Watanabe and Tanaka, 2007). A few studies concentrated on the industrial development of the Yangtze River Economic Belt. Wu and Dong (2014) used the ML index to measure the industrial TFP of the Yangtze River Economic Belt, but they did not consider environmental factors. Wang *et al*. (2015) used the ratio of industry output and environmental pressure to evaluate the eco-industrial productivity of the Yangtze River Economic Belt from the perspective of green development for the first time. However, none of the studies addressed the evolution of the spatial pattern.

To conclude, the practical and theoretical significance of research on the industrial green development of the Yangtze River Economic Belt has become evident. However, relevant research is scarce, as most studies are about measurement methods and empirical analysis focusing on China, rather than the belt. First, their methods are incomplete in that the treatment of undesirable output is not scientifically sound. Second, almost all studies are at the industry or province level. But the city is the most important spatial unit of modern economic development, and could therefore reveal deeper and more detailed information than the former. Third, very few address spatial pattern. The Yangtze River flows through eastern, central, and western China and its spatial pattern should reveal the evolution in greater detail. Thus, we use the data of 108 prefecture- or above city-level areas and a directional slacks-based measure of efficiency and inverse distance weighting method to analyze the industrial green spatial pattern of the Yangtze River Economic Belt from 2003–2013, aiming to bridge the gap in current research and discover spatial evolution rules.

2 Materials and Methods

2.1 Study area

The Yangtze River Economic Belt covers 11 provinces and 108 prefecture- or above city-level areas. The 108 prefecture- or above city-level areas include two municipalities (Shanghai and Chongqing) and 106 prefecture-level cities. Hereafter, 'cities' is short for 'prefecture- or above city-level areas'. The 108 cities could be classified into three urban agglomerations (Fig. 1). The Pan-Chengdu-Chongqing urban agglomeration is located in the upstream area of the Yangtze River and the western area of China, and has 31 cities of Sichuan, Yunnan, Guizhou provinces, and Chongqing municipality. The Central Triangle urban agglomeration is located in the midstream area of the Yangtze River and the central area of China, including 52 cities of Hunan, Hubei, Jiangxi, and Anhui provinces. Although Anhui Province has been classified into the Pan-Yangtze River Delta urban agglomeration, its economic development level remains the same as the Central Triangle urban agglomeration. We still classified Anhui Province into the

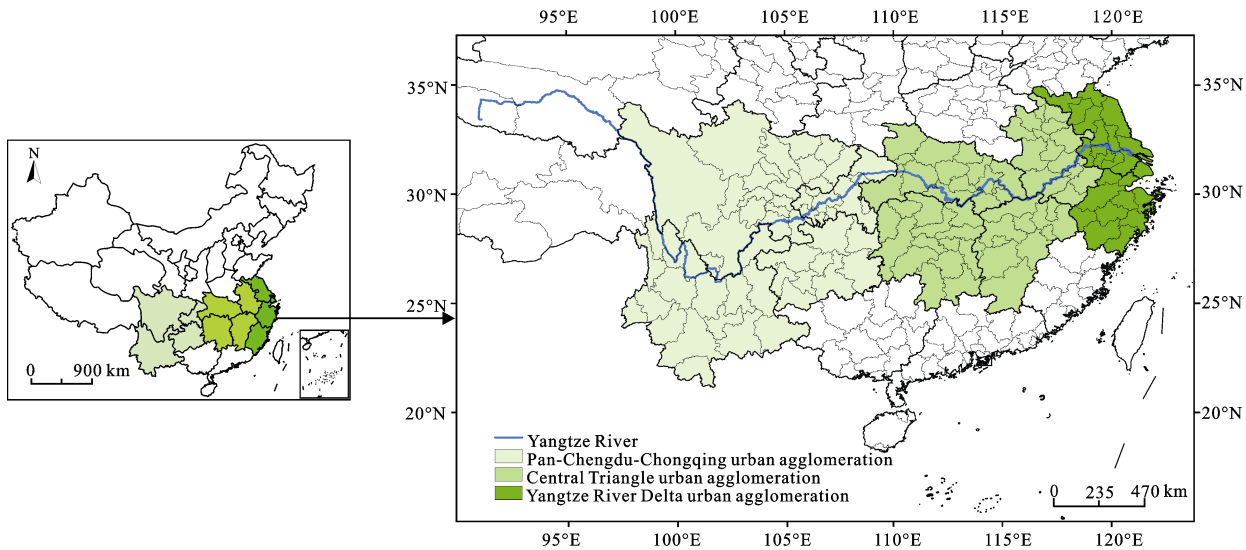

Fig. 1 Location of Yangtze River Economic Belt

Central Triangle urban agglomeration. The Yangtze River Delta urban agglomeration is located in the downstream area of The Yangtze River and the eastern area of China, including 25 cities of Shanghai, Jiangsu, and Zhejiang provinces.

2.2 Study methods

The industrial GTFP is given by the directional slacks-based measure of efficiency and MaxDEA Pro software. Then, inverse distance weighting method and ArcGIS 10.0 software are used to analyze the spatial pattern of the industrial GTFP to discover the spatial evolution rules.

2.2.1 Directional slacks-based measure of efficiency (SBM)

A non-oriented directional SBM of efficiency could deal with undesirable output and slack variable without setting input-oriented or output-oriented in advance. The non-oriented SBM function is as follows:

$$\min \rho^* = \frac{1-\frac{1}{n}\sum_{i=1}^{n}\frac{s_i^-}{x_{i0}}}{1+\frac{1}{u+v}\left(\sum_{j=1}^{u}\frac{s_j^g}{y_{j0}^g}+\sum_{j=1}^{v}\frac{s_j^b}{y_{j0}^b}\right)}$$
$$\begin{aligned} s.t.\quad & x_0 = X\lambda + s^- \\ & y_0^g = Y^g\lambda - s^g \\ & y_0^b = Y^b\lambda - s^b \\ & \lambda, s^-, s^g, s^b \geq 0 \end{aligned} \tag{1}$$

where ρ^* is the efficiency; x is input; y^g is desirable output; y^b is undesirable (bad) output; s is the slack variable; i and j are the decision-making unit; n, u and v are the quantity of the decision-making units; λ is the coefficient of each decision-making unit. ML index could explain the change of the efficiency:

$$ML_t^{t+1} = \sqrt{\frac{1+\vec{D}_0^t(x^t, y^t, b^t; g^t)}{1+\vec{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})}} \times \sqrt{\frac{1+\vec{D}_0^{t+1}(x^t, y^t, b^t; g^t)}{1+\vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})}} \tag{2}$$

where ML_t^{t+1} is the ML index from t year to t+1 year, $\vec{D}_0^t$ and $\vec{D}_0^{t+1}$ is the directional distance function in t year and t+1 year, The ML index measures the change of GTFP, not GTFP itself. Thus, several steps should be taken to obtain the GTFP. Typically, studies have assumed the GTFP of each decision-making unit to be 1 in the base year, and is then multiplied by the ML index to obtain the approximate GTFP (Li *et al*., 2013). However, this assumption neglects the difference in the base year. To improve this method, we assume the industrial GTFP of each city to be its efficiency in the base year instead of 1.

Variables are selected as follows: input variables include labor input, capital input, and energy input. Labor input is the total employed persons in the industry; capital input is the sum of current assets and fixed assets

of industrial enterprises; energy input is the industrial electricity consumption. Output variables include the desirable output of the gross industrial output value, and the undesirable outputs of industrial wastewater, sulfur dioxide, and soot emission. The data for this study were from the China City Statistical Yearbook. The study period covers 2003–2013 because variables like industrial wastewater, sulfur dioxide, and soot emission were first recorded in 2003. Gross industrial output value and capital are adjusted to the price of 2003 according to the accumulative price index.

2.2.2 Inverse distance weighting (IDW)

Common spatial interpolation methods include inverse distance weighting (IDW), polynomial interpolation and Kriging interpolation, among which IDW is the most convenient method that does not involve any additional settings, unreasonable values, or long operation time. The theoretical base of IDW is drawn from the first law of geography, and the name of this method was motivated by the weighted average applied, as it resorts to the inverse of the distance to each known point when assigning weights (Li *et al*., 2012). It is a weighted moving average method (Lu *et al*., 2013) and is set to be an exact interpolator (smoothing parameter is set to be zero), with the search radius at the maximum extent of data (Tomczak, 1998).

$$Z^*(x_0) = \sum_{i=1}^{n} \frac{1}{(D_i)^k} Z(x_i) \Big/ \sum_{i=1}^{n} \frac{1}{(D_i)^k} \tag{3}$$

where $Z^*(x_0)$ is interpolation, x_0 is the sample point; $Z(x_i)$ is the value of point i; D_i is the distance; i is the point; n is the amount of sample points; k is the power of distance. Like many spatial statistical measures, IDW is also developed to evaluate the local or neighborhood situation (Getis and Ord, 1992). IDW has a comparatively higher requirement on the amount of sample points, and only dense sample points could IDW give perfect outcome (Watson and Philip, 1985).

3 Results

3.1 Industrial GTFP of Yangtze River Economic Belt

The average industrial GTFP of Yangtze River Economic Belt, Yangtze River Delta, Central Triangle, and Pan-Chengdu-Chongqing urban agglomeration from 2003–2013 are 0.891, 1.508, 0.830, and 0.656 respectively (Table 1). This shows a significant difference among the three urban agglomerations with the Yangtze River Delta urban agglomeration ranking first and the Pan-Chengdu-Chongqing urban agglomeration lagging behind. The main cause of this significant difference is the different industrialization stages. Industrialization often develops from extensive stage with large energy consumption and environmental pollution, to intensive stage with higher energy efficiency and environmental protection. This can be seen in the rise of GTFP from the primary stage of industrialization to the stage of intensive development in late industrialization. The developed regions of eastern China, represented by Shanghai, Nanjing, and Suzhou, have entered the late stage of industrialization (Huang, 2014) and have formed comparatively complete green industrial systems, contributing to the high industrial GTFP of the Yangtze River Delta urban agglomeration. Underdeveloped regions of central and western China are mainly in the middle stage of industrialization and their industrial GTFP is lower than that of the Yangtze River Delta urban agglomeration.

The annual industrial GTFP growth of Yangtze River Economic Belt, Yangtze River Delta, Central Triangle, and Pan-Chengdu-Chongqing urban agglomeration from 2003–2013 is 11.9%, 13.3%, 14.1%, and 7.2% respectively. It is worth noting that there are two significant changes. The first change is that the growth rate remains above 0 except in 2008–2009, when it is –5.9%. This could be closely related to China's economic growth. Due to the breakout and spread of the subprime mortgage crisis, China's GDP growth declined from 14.2% in 2007 to 9.6% in 2008 and 9.2% in 2009, along with problems like unemployment, depressed residential private investment, decreased profit margins, and a serious shortage of funds. It lead to insufficient industrial input (capital, labor, *etc*.), especially investment in R&D, machinery, and equipment purchases, which plays a decisive role in industrial technical progress and industrial GTFP growth. Another significant change is the ever-decreasing growth rate since 2010. The industrial GTFP growth decreased in 2010–2013 from 22% to 9.2%, 3.7%, and even 0.7% year on year. Under the background of the European debt crisis, the weak recovery of the American economy, and complex situations in China, China's economy went into the 'new normal', with GDP growth rate decreasing from 9.3% in

Table 1 Industrial GTFP of Yangtze River Economic Belt and three urban agglomerations

Year	Yangtze River Economic Belt		Yangtze River Delta urban agglomeration		Central Triangle urban agglomeration		Pan-Chengdu-Chongqing urban agglomeration	
	GTFP	Growth (%)	GTFP	Growth (%)	GTFP	Growth (%)	GTFP	Growth (%)
2003	0.446	–	0.694	–	0.380	–	0.409	–
2004	0.543	21.8	0.885	27.6	0.470	23.8	0.466	14.0
2005	0.618	14.0	1.001	13.1	0.543	15.5	0.520	11.7
2006	0.725	17.4	1.210	20.9	0.633	16.7	0.603	15.9
2007	0.862	18.9	1.482	22.5	0.770	21.6	0.674	11.7
2008	1.044	21.1	1.742	17.6	0.937	21.7	0.830	23.1
2009	0.983	–5.9	1.764	1.2	0.914	–2.5	0.694	–16.4
2010	1.200	22.0	2.234	26.7	1.111	21.6	0.827	19.2
2011	1.310	9.2	2.132	–4.5	1.386	24.8	0.803	–2.9
2012	1.358	3.7	2.366	11.0	1.457	5.1	0.771	–4.0
2013	1.368	0.7	2.412	1.9	1.416	–2.9	0.817	6.0
Mean	0.891	11.9	1.508	13.3	0.830	14.1	0.656	7.2

2011 to 7.7% in 2012 and 2013, going below 8% for the first time in the 21st century.

The industrial GTFP of the Yangtze River Economic Belt has experienced drastic changes after 2008, and would surely result in a spatial pattern quite different patterns that existed prior to 2008. Thus, we divided 2003–2013 into two stages, 2003–2008 and 2009–2013.

3.2 Form of tripartite pattern in 2003–2008

A tripartite pattern has formed in 2003–2008 (Fig. 2). Green poles gathered around some capital cities gradually and formed three green areas centering on Chengdu, Changsha-Nanchang, and the Yangtze River Delta core area, which are in the upstream, midstream, and downstream regions of the Yangtze River respectively. The Yangtze River Delta core area consists of 16 cities: Shanghai, Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yangzhou, Zhenjiang, Taizhou, Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Zhoushan, and Taizhou. In 2003, green poles gathered in the western and eastern areas of the Yangtze River Economic Belt. The eastern green area is the Yangtze River Delta core area in the Yangtze River Delta urban agglomeration and the western green area is Lijiang-Yuxi-Qujing-Kunming in the Pan-Chengdu-Chongqing urban agglomeration. Some green poles like Nanchong, Bazhong, Suizhou, and Yueyang dispersed in central and western areas. This spatial pattern is not stable, because only the eastern green area has formed around capital cities while other green poles gathered around non-capital cities, especially the western green area. In 2004, the western green area dissipated. Dispersed green poles like Zhaotong, Qujing, Ziyang, Nanchong, Suining, and Guang'an have appeared and gathered around Chengdu gradually, forming the comparatively stable upstream green area of Chengdu-Mianyang-Neijiang-Suining-Nanchong. At the same time, dispersed green poles in the Central area like Suizhou and Yueyang have gradually gathered around Changsha and Nanchang, and formed the midstream green area of Changde-Yueyang-Changsha-Hengyang-Chenzhou-Ganzhou-Fuzhou-Nanchang in 2008. The eastern green area of the Yangtze River Delta core area centering on capital cities remains consistently stable and dominates as the most powerful downstream green area. So far, a tripartite pattern of three green areas around capital cities distributed in the upstream, midstream, and downstream regions of the Yangtze River has formed.

3.3 Form of multi-poles pattern in 2009–2013

The tripartite pattern changed to a multi-poles pattern in 2009–2013 (Fig. 3). The upstream green area remains stable, while the diffusion effect of the green poles in midstream and downstream green areas has appeared and created numerous new green poles, resulting in vanishing boundaries of the two green areas, and integrating them. In the end, three green areas dissipated and green poles continuously and densely spread in the middle and downstream areas. Under the impact of the subprime mortgage crisis, the industrial green development

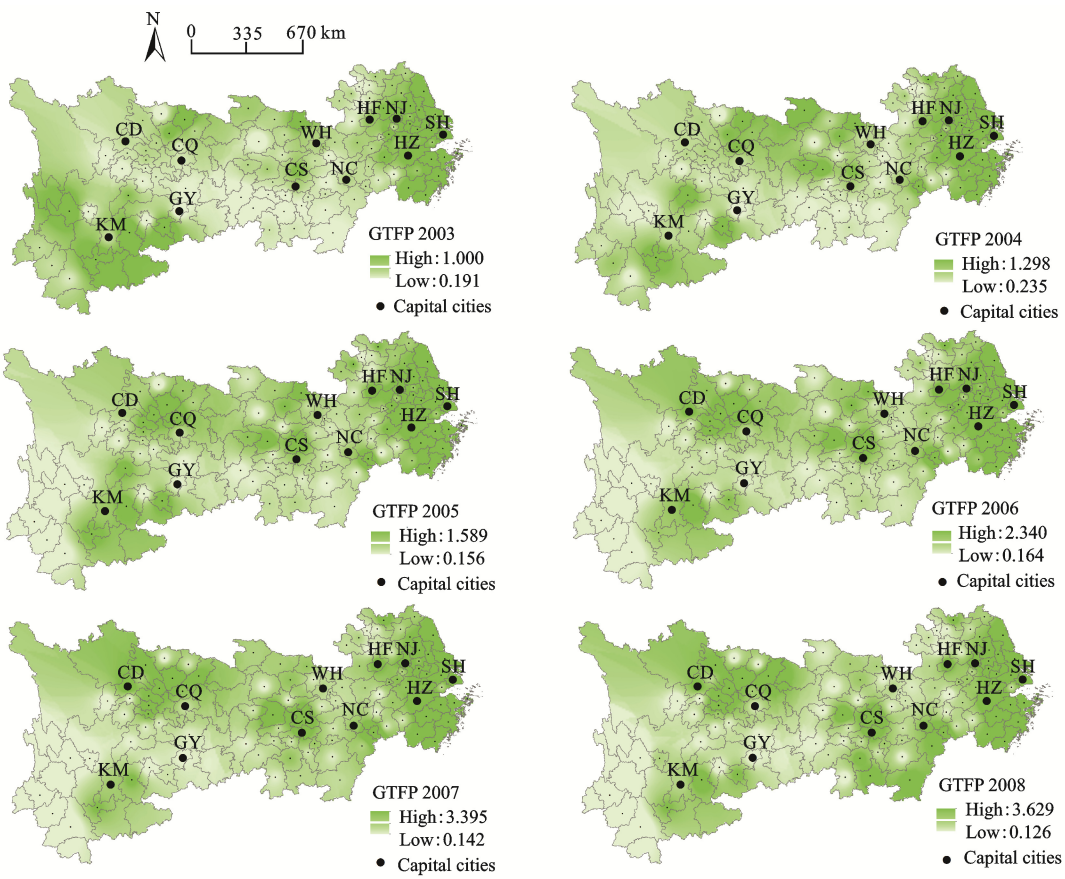

Fig. 2 Industrial green spatial pattern of the Yangtze River Economic Belt, 2003–2008. GTFP, Green total factor productivity; KM, CD, GY, CQ, CS, WH, NC, HF, NJ, HZ and SH is short for Kunming, Chengdu, Guiyang, Chongqing, Changsha, Wuhan, Nanchang, Hefei, Nanjing, Hangzhou and Shanghai

of the Yangtze River Economic Belt has experienced great challenges. The tripartite pattern in the first stage has dissipated gradually. In 2009, the three green areas in the upstream, midstream and downstream areas have all narrowed down, and the amount of green poles sharply decreased. The dilemma has remained for years, showing the long and deep impact of the subprime mortgage crisis. Then in 2011–2012, the industrial green spatial pattern has started to improve, new green poles in the midstream and downstream areas have emerged and contributed to the form of the multi-poles pattern. However, the Pan-Chengdu-Chongqing urban agglomeration experienced trouble in the second stage. Its spatial evolution differs from other regions. The quantity of green poles in the Pan-Chengdu-Chongqing urban agglomeration has been decreasing since 2009 and there are no more dispersed green poles except the green area in 2013, whereas several new green poles have arisen in midstream and downstream areas since 2011. Besides green poles like Changde, Yueyang, Changsha, Hengyang, Chenzhou, Ganzhou, Fuzhou, Nanchang, and 16 cities of the Yangtze River Delta core area in green areas, new poles like Wuhan, Xiangyang, Jingmen, and Huaihua have emerged, enlarging and integrating the midstream and downstream green areas. In the end, the tripartite pattern changes to a multi-poles pattern with green poles distributed continuously and densely in the midstream and downstream areas.

4 Discussion

4.1 Cause of tripartite pattern in 2003–2008

The growth pole and core-periphery theories of new economic geography could explain the cause of the tripartite pattern (Perroux, 1950; Kuklinski and Petrella, 1972; Higgins and Savoie, 1988; Baldwin *et al.*, 2003). According to the growth pole theory, growth does not happen everywhere at the same time. It tends to take place in some growth points or growth poles at first, and then the growth poles promote the growth of the whole

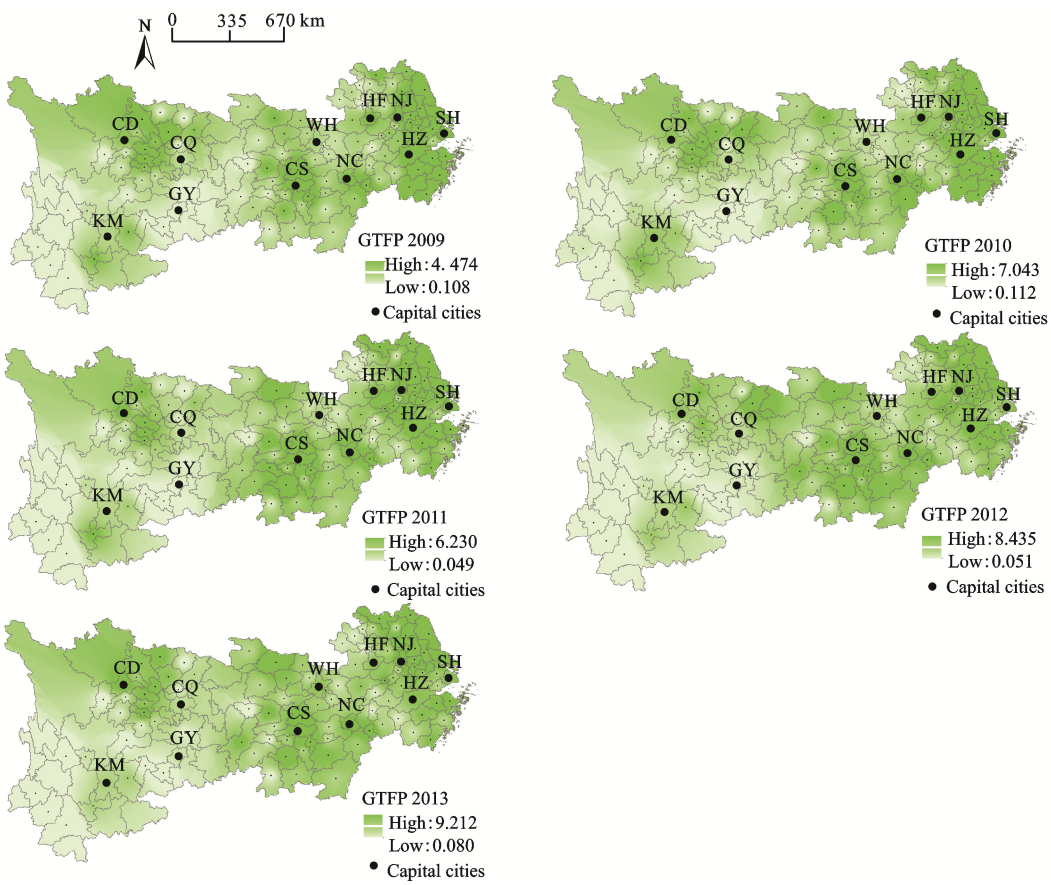

Fig. 3 Industrial green spatial pattern of the Yangtze River Economic Belt, 2009–2013. GTFP, Green total factor productivity; KM, CD, GY, CQ, CS, WH, NC, HF, NJ, HZ and SH is short for Kunming, Chengdu, Guiyang, Chongqing, Changsha, Wuhan, Nanchang, Hefei, Nanjing, Hangzhou and Shanghai

region through its diffusion effect. In the beginning, comparatively developed regions like capital cities have a stronger industrial economic base and preferential policy, and could therefore attract resources from surrounding regions. Resources like capital, labor, technology and talent flow from underdeveloped to developed regions and promote the growth of developed regions, leading to what is called polarization effect. It causes geographical agglomeration and economies of scale, which would result in the form of growth poles. At the same time, growth poles could drive the development of surrounding regions through a series of linkage mechanisms like the multiplier effect. This is called the diffusion effect. The two effects exit simultaneously and both play important roles in the industrial green spatial pattern of the Yangtze River Economic Belt. In the first stage, polarization effect has played a more important role than diffusion effect, forming several green poles among capital cities and contributing to the form of the tripartite pattern, which is also a typical core-periphery pattern. Developed regions like capital cities or growth poles become the strong 'core' and surrounding regions become the supporting 'periphery'. The tripartite pattern could be further divided into three core-periphery patterns. The first core-periphery pattern is the upstream green area centered on Chengdu, the second core-periphery pattern is the midstream green area centered on Changsha and Nanchang, and the third core-periphery pattern is the downstream green area centered on 16 core cities of the Yangtze River Delta. The Yangtze River Delta is one of the most developed regions in China and the industrial green development of its core 16 cities is obviously better than other regions. However, it leads to a comparatively insignificant core-periphery pattern in Fig. 2, since the 'core' is not one city but a city group.

The characteristic of spatial evolution is green poles gathering around capital cities gradually, with the capital

city being the 'core' of the tripartite pattern in the first stage (Fig. 2). Green areas centered on capital cities are more stable and have a stronger driving effect than that around non-capital cities. Among 11 capital cities, only Shanghai, Nanjing, and Hangzhou have been green poles since 2003, keeping the downstream green area consistently stable, while the upstream green area around non-capital cities dissipates in 2004. Hefei, Chengdu, Changsha, and Nanchang became new green poles in 2005, 2006, 2007, and 2008 respectively, and increased the quantity of green poles that are capital cities from three to seven, contributing to the form of the tripartite pattern. As Table 2 shows, the annual industrial GTFP growth rates of capital cities Hefei, Chengdu, Changsha, and Nanchang, which are new green poles, are 30.5%, 36.0%, 39.5%, and 27.8% respectively. Their growth rates are apparently higher than other cities. However, despite great improvement, the industrial green development of capital cities still needs to be intensified. The annual growth rates of Chongqing, Guiyang, Wuhan, and Kunming, which are the capital cities that have not become green poles, are only 13.8%, 19.2%, 20.9% and 23.4%, being even lower than most non-capital cities. Among these, three capital cities are in the Pan-Chengdu-Chongqing urban agglomeration, indicating the lack of driving effects from capital cities. The spatial evolution of the Pan-Chengdu-Chongqing urban agglomeration may differ from other regions in the next stage.

Table 2 Annual industrial GTFP growth of 108 cities in Yangtze River Economic Belt, 2003–2008

Urban agglomeration	City	Growth (%)	City	Growth (%)	City	Growth (%)	City	Growth (%)
Yangtze River Delta urban agglomeration	Huzhou	39.7	Nantong	32.6	Xuzhou	32.4	Jinhua	29.2
	Shaoxing	27.8	Yangzhou	27.7	**Hangzhou**	**25.4**	Zhenjiang	23.1
	Zhoushan	22.9	Changzhou	22.9	Huai'an	22.4	Quzhou	20.4
	Lianyungang	19.7	Wenzhou	18.9	Yancheng	17.1	**Nanjing**	**17.0**
	Lishui	15.1	Taizhou	15.0	Taizhou	14.0	Suzhou	13.4
	Shanghai	**13.3**	Ningbo	13.1	Suqian	10.1	Wuxi	9.5
	Jiaxing	9.1						
Central Triangle urban agglomeration	Yingtan	55.0	Ganzhou	48.2	Hengyang	45.5	Chenzhou	42.6
	Changsha	**39.5**	Changde	37.1	Yueyang	34.6	Fuzhou	33.6
	Hefei	**30.5**	Pingxiang	29.0	Tongling	28.3	**Nanchang**	**27.8**
	Jingmen	27.6	Lu'an	27.3	Yichun	25.6	Huangshi	25.2
	Xiangtan	24.6	Jiujiang	24.0	Shaoyang	23.2	Xiangyang	22.2
	Xinyu	22.1	Yichang	21.8	Ma'anshan	21.7	Zhuzhou	21.4
	Xuancheng	21.1	**Wuhan**	**20.9**	Huaihua	19.8	Huaibei	19.7
	Loudi	19.2	Shangrao	18.1	Anqing	15.5	Bozhou	15.1
	Yiyang	14.9	Sùzhou	14.3	Bengbu	14.3	Huainan	13.8
	Fuyang	12.2	Xianning	11.3	Huanggang	11.1	Jingzhou	10.5
	Jingdezhen	10.4	Ji'an	10.1	E'zhou	9.1	Huangshan	7.7
	Yongzhou	7.0	Shiyan	6.4	Zhangjiajie	6.0	Xiaogan	5.4
	Wuhu	5.2	Suizhou	2.4	Chizhou	0.8	Chuzhou	0.3
Pan-Chengdu-Chongqing urban agglomeration	Neijiang	53.5	Dazhou	48.9	Panzhihua	36.9	**Chengdu**	**36.0**
	Suining	35.9	Mianyang	34.4	Nanchong	29.6	Ziyang	29.4
	Guang'an	28.8	Zigong	28.3	**Kunming**	**23.4**	Leshan	20.1
	Deyang	19.3	**Guiyang**	**19.2**	Yibin	16.7	Qujing	16.6
	Guangyuan	16.6	Zunyi	16.0	Liupanshui	14.4	Luzhou	13.8
	Chongqing	**13.8**	Anshun	10.8	Yuxi	10.0	Meishan	6.1
	Ya'an	2.1	Zhaotong	–0.3	Pu'er	–1.1	Lincang	–5.2
	Baoshan	–8.4	Bazhong	–12.5	Lijiang	–34.1		

Notes: Growth is the geometric mean of the growth rates from 2003–2008; the 11 cities in bold are the capital cities in the Yangtze River Economic Belt

Additionally, along with the form of the tripartite pattern, great improvements in the Central Triangle urban agglomeration should be noted. New green poles that are capital cities include Hefei, Chengdu, Changsha, and Nanchang, among which, three are in the Central Triangle urban agglomeration. The average growth rate of Hefei, Changsha, and Nanchang is higher than 30% and the rise of the Central Triangle urban agglomeration is the most significant change when comparing the spatial pattern in 2003 with that of 2008 in Fig. 2. This is the result of China's regional strategy and policy. With superior geographical location and preferential policy, eastern China, represented by the Yangtze River Delta, has been the growth pole, promoting China's industrial economic growth for decades. This has also led to negative effects like considerable regional economic difference and insufficient economic growth impetus. To solve these problems and build a new growth pole, the government has assigned great importance to developing central China. Since the introduction of 'the rise of central China' strategy in 2004, the State Council of China has issued the 'Guidelines on stimulating the rise of central China' and the 'Guidelines on stimulating the rise of central China vigorously'. It has established two 'two-oriented society' comprehensive reform pilot areas (Wuhan city circle and Changsha-Zhuzhou-Xiangtan city group) in central China. It provides an opportunity for industrial green development in the Central Triangle urban agglomeration and improves the industrial GTFP of Changsha, Wuhan and Nanchang. Owing to the driving effect of capital cities, the industrial GTFP of the Central Triangle urban agglomeration has increased significantly and contributed greatly to the form of the tripartite pattern.

4.2 Cause of multi-poles pattern in 2009–2013

Under the impact of the subprime mortgage crisis, the industrial green spatial pattern changed significantly after 2008. However, owing to varying industrial GTFP and driving effects of capital cities, the three urban agglomerations have experienced different changes. First, regions with higher industrial GTFP often indicate strength in industrial structure, product competitiveness, financial systems, supply chain management and other key elements that form the capability to cope with economic fluctuations. These regions were able to handle the subprime mortgage crisis. The industrial GTFP of the Pan-Chengdu-Chongqing urban agglomeration decreased by 16.4%, while the Central Triangle and the Yangtze River Delta urban agglomerations with higher industrial GTFP only decreased by 2.5% or even increased by 1.2% (Table 1). Secondly, the driving effect of capital cities directly affects the polarization effect and diffusion effect of the green poles. However, in the Pan-Chengdu-Chongqing urban agglomeration, three out of four capital cities have not become green poles, while the capital cities in the Central Triangle and the Yangtze River Delta urban agglomerations have all become green poles. Thus, with lower industrial GTFP and weaker driving effect of capital cities, the spatial evolution of the Pan-Chengdu-Chongqing urban agglomeration differs from other regions in 2009–2013. The diffusion effects of capital cities in the Yangtze River Delta and Central Triangle urban agglomerations have been intensified, resulting in numerous new green poles and high industrial GTFP growth. However, the polarization effect still leads in the Pan-Chengdu-Chongqing urban agglomeration as the green poles intensify while other regions grow slowly or even decline. In addition, new economic geography theory emphasizes the critical roles of agglomeration and dispersion in the form of spatial patterns (Neary, 2001; Overman and Ioannides, 2001). The centripetal force from developed regions could attract resources like capital, labor, talent, technology, resulting in agglomeration. Conversely, centrifugal force leads to dispersion (Tabuchi, 1998). Along with the stronger diffusion effects, centripetal forces such as Marshall externalities, economies of scale or industrial clusters in the Yangtze River Delta and the Central Triangle urban agglomerations are comparatively stronger than the Pan-Chengdu-Chongqing urban agglomeration. This leads to differing regional performance under the subprime mortgage crisis, and results in numerous new green poles in the midstream and downstream areas.

The characteristic of spatial evolution of the Yangtze River Economic Belt in the second stage is the emergence of numerous green poles in the midstream and downstream areas, indicating the trend of green poles moving towards the east (Fig. 3). This spatial pattern change is closely related to the polarization effect in the Pan-Chengdu-Chongqing urban agglomeration and the diffusion effect in the Yangtze River Delta and the Central Triangle urban agglomerations. When the diffusion effect that could promote the growth of non-capital cit-

ies is stronger than the polarization effect that could promote the growth of capital cities, spatial evolution enters a comparatively higher stage. The main effect of the growth poles has changed from 'receive' to 'give', thereby boosting the growth of the whole region. It could be displayed as the comparatively decreased growth rates of capital cities alongside increased growth rates of non-capital cities. The growth rates of the capital cities in the Yangtze River Delta and the Central Triangle urban agglomerations in 2009–2013 (Table 3) are mostly lower than 2003–2008 (Table 2) when compared with the growth rates of non-capital cities, while the average growth rate of these two urban agglomerations still remains high (Table 1). It has demonstrated the diffusion effect of the green poles that contributes to the lower growth rates of capital cities, higher growth rates of non-capital cities and higher aggregate growth rate of the urban agglomeration. However, this is different for the Pan-Chengdu-Chongqing urban agglomeration. The annual growth rates of four capital cities Chengdu, Guiyang, Chongqing and Kunming have increased significantly and are ranked 3, 4, 5, 9 respectively, but the growth rate of half of the non-capital cities has declined, and the aggregate growth rate of the urban agglomeration has decreased as well. It may demonstrate the leading role of the polarization effect and the weak driving effect of the capital cities. The main effect of the growth poles is still 'receive' rather than 'give'. As a result, the diffusion effect in the Yangtze River Delta and the Central Triangle urban agglomerations has created many

Table 3 Annual industrial GTFP growth of 108 cities in Yangtze River Economic Belt, 2009–2013

Urban agglomeration	City	Growth (%)	City	Growth (%)	City	Growth (%)	City	Growth (%)
Yangtze River Delta urban agglomeration	Xuzhou	37.7	Changzhou	31.3	Huai'an	30.0	Lianyungang	23.1
	Taizhou	18.1	Zhoushan	15.0	Zhenjiang	14.6	Nantong	9.8
	Ningbo	9.5	Yancheng	8.3	Jiaxing	7.5	Jinhua	5.1
	Suqian	2.6	**Nanjing**	**2.6**	Wuxi	2.5	**Shanghai**	**0.5**
	Yangzhou	0.5	**Hangzhou**	**0.1**	Shaoxing	0.0	Wenzhou	–0.1
	Quzhou	–1.1	Suzhou	–2.4	Tāizhou	–9.4	Huzhou	–10.1
	Lishui	–10.3						
Central Triangle urban agglomeration	Xiangyang	40.2	Huaihua	38.2	Ji'an	35.8	Pingxiang	30.1
	Tongling	21.1	E'zhou	20.8	Xianning	20.1	Bengbu	19.5
	Wuhan	**19.4**	Yichang	18.3	**Nanchang**	**16.8**	Anqing	16.2
	Chuzhou	15.6	Hengyang	14.6	**Changsha**	**14.1**	Shiyan	12.2
	Zhuzhou	11.9	Shangrao	11.7	Jingmen	10.7	Xiangtan	10.6
	Jingzhou	10.5	Huaibei	9.9	Jiujiang	9.8	Xiaogan	9.5
	Chizhou	7.4	Suizhou	7.3	Ma'anshan	7.0	Suzhou	6.7
	Lu'an	6.1	Yichun	5.8	Xuancheng	5.3	Wuhu	4.7
	Yiyang	4.5	Shaoyang	4.5	Yingtan	4.3	Changde	4.1
	Huangshi	3.7	Huangshan	3.2	Fuyang	3.0	Yongzhou	2.5
	Hefei	**1.4**	Huainan	1.3	Huanggang	1.1	Xinyu	0.4
	Fuzhou	0.2	Jingdezhen	–0.9	Loudi	–1.8	Yueyang	–3.2
	Bozhou	–6.1	Ganzhou	–6.4	Chenzhou	–6.8	Zhangjiajie	–20.2
Pan-Chengdu-Chongqing urban agglomeration	Guangyuan	44.2	Zigong	29.9	**Chengdu**	**17.1**	**Guiyang**	**12.5**
	Chongqing	**11.6**	Luzhou	11.4	Deyang	11.4	Ziyang	10.0
	Kunming	**9.6**	Meishan	4.9	Suining	4.0	Liupanshui	2.8
	Mianyang	2.3	Zunyi	2.2	Leshan	1.7	Yibin	1.1
	Panzhihua	–1.5	Bazhong	–1.9	Yuxi	–2.1	Nanchong	–2.8
	Ya'an	–3.8	Pu'er	–5.9	Qujing	–6.0	Lijiang	–8.8
	Baoshan	–10.6	Guang'an	–11.3	Neijiang	–12.3	Zhaotong	–14.0
	Dazhou	–16.3	Lincang	–19.3	Anshun	–36.7		

new green poles, resulting in vanishing boundaries of the two green areas and integrating them. However, the Pan-Chengdu-Chongqing urban agglomeration lags behind and remains at an early stage of forming green poles under the polarization effect. The tripartite pattern has changed to a multi-poles pattern where green poles spread continuously and densely in the midstream and downstream areas.

5 Conclusions

The subprime mortgage crisis and China's 'new normal' both had significant negative effects on the industrial GTFP growth of the Yangtze River Economic Belt, leading to the varying spatial pattern between 2003–2008 and 2009–2013. In 2003–2008, green poles gathered around some capital cities gradually and formed a tripartite pattern, which was a typical core-periphery pattern. This is attributed mainly to the innate advantage of capital cities and 'the rise of central China' strategy. In 2009–2013, the tripartite pattern changed to a multi-poles pattern where green poles spread continuously and densely in the midstream and downstream areas. This was caused by the leading effect of green poles with regional difference. This leading effect in midstream and downstream areas has changed from polarization to diffusion. However, the polarization effect still leads in the upstream area.

Different industrial green spatial patterns indicate different development paths. Generally, development paths go through periodic cycles of imbalance and balance. The Yangtze River Economic Belt is now in the unbalanced development stage due to the significant differences among the three urban agglomerations. The three urban agglomerations should select different spatial modes for further development. The Yangtze River Delta urban agglomeration almost experienced a complete cycle of imbalance to balance. This indicates that several cities with innate advantages become the green poles first and then drive the industrial green development of the whole region through the diffusion effect, finally realizing the change from imbalance to balance. It should enter a higher level of imbalance to obtain a new driving force that will stimulate industrial green development. The developed 16 core cities of the Yangtze River Delta should bear the responsibility of building new green poles to enter a new cycle. For the Central Triangle urban agglomeration, it closely follows the Yangtze River Delta urban agglomeration, and now stays at the key stage of transforming from imbalance to balance. The diffusion effects of the green poles like Wuhan, Changsha, Nanchang, Hefei and other new green poles should be intensified to realize balanced development. However, the Pan-Chengdu-Chongqing urban agglomeration falls far behind. The driving force of the unbalanced development is not strong enough to drive the development of other regions. The industrial green development of capital cities, especially Chengdu and Chongqing, should be assigned great importance. Only the green poles that are strong enough can boost the development of the whole region and accelerate the completion of the primary cycle of imbalance and balance.

Based on the conclusions and implications above, some suggestions regarding China's new development concepts of innovation, coordination, green, openness, and sharing are as follows.

Innovate towards a new pattern of industrial cooperation, such as 'industrial enclaves' that can intensify regional development. The diffusion effect helps create many new poles and form the multi-poles pattern of the Yangtze River Economic Belt. To intensify the diffusion effect of developed areas, 'industrial enclaves' should be built between developed and underdeveloped areas. The governments of the Pan-Chengdu-Chongqing and Central Triangle urban agglomerations should build an appropriate benefit-sharing mechanism, and accept industries from the Yangtze River Delta through the industrial enclaves. The governments in the Yangtze River Economic Belt may reach a win-win result by introducing enterprises that match with the leading local and supporting industries, thereby improving the scale and efficiency of the local industrial economy, and providing space and resources for industrial transformation and upgrading in the Yangtze River Delta.

Strengthen policy support for the Pan-Chengdu-Chongqing urban agglomeration to promote coordinated industrial green development in the Yangtze River Economic Belt. The industrial green development of the Pan-Chengdu-Chongqing urban agglomeration lags behind, and the unbalanced green spatial pattern is due to the insufficient support of upstream enterprises. Given this, the government should issue a macro-strategic plan and provide practical policy guidance to support the

industrial green development of the agglomeration. This includes measures such as the construction of a 'two-oriented society', the green transformation of traditional industries, the development of emerging strategic industries, and the cluster-type development of special industries. Moreover, capital cities like Chongqing, Chengdu, Guiyang, and Kunming should have access to more preferential policy.

Build an industrial green development system to promote industrial green transformation in the Yangtze River Economic Belt. The Yangtze River Delta is in the late stage of industrialization. The government should issue guiding policies to encourage the Yangtze River Delta to help the Pan-Chengdu-Chongqing and the Central Triangle urban agglomerations with their industrial green transformation. Some possible measures include building the industrial green development system from the perspective of an industrial base, transforming and upgrading traditional industries, and the recycling of three areas' industrial wastes. This will accelerate their progress from the middle to the late stage in industrialization, as well as increase the speed of industrial green transformation in the Yangtze River Economic Belt.

Accelerate reforms in the integration of regional customs clearance to promote resource-shared in the Yangtze River Economic Belt. In this regard, the government should build the center of regional customs clearance in the Yangtze River Economic Belt and establish uniform declaration, risk prevention and control, professional documents' examination, and site order-receiving platforms. This will form a management mechanism of integration that covers all processes of customs clearance in the belt. This will enable the integration of clearance operations and facilitate the construction of resource-sharing channels for industrial green development in the Yangtze River Economic Belt.

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