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Different types of industrial agglomeration and green total factor productivity in China: do institutional and policy characteristics of cities make a difference?

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Abstract

This paper applies panel data of 281 prefecture-level cities in China from 2004 to 2017 to calculate the green total factor productivity (GTFP) at the city level. Then, it examines the influences of various forms of industrial agglomeration on GTFP and its two decomposition factors. The results demonstrate that the agglomeration of the manufacturing industry rather than producer services can effectively improve the GTFP of cities mainly through stimulating internal technological progress. However, the collaborative agglomeration of manufacturing and producer services has a significant positive correlation with GTFP. In addition, the heterogeneity analysis shows that for cities with institutional and policy advantages, collaborative agglomeration can play a more substantial effect. But, for ordinary cities, manufacturing agglomeration is more beneficial to furthering the growth of GTFP.

Keywords: Industrial agglomeration, Collaborative agglomeration, Manufacturing, Producer services, Green total factors productivity, Decomposition factors

Introduction

In the context of climate change and energy issues becoming the most challenging concerns for all countries [26], the Chinese government is also making efforts to provide Chinese solutions for global sustainable development [2, 89]. In order to increase energy conservation and emission reduction while ensuring steady economic growth, the Chinese government has focused on supply-side reform [42]. It has not only vigorously supported the green upgrading of manufacturing and service industries, but also proposed to encourage the in-depth integration of advanced manufacturing and modern service industries recently [74].

Agglomeration theory believes that industrial agglomeration (IA) has a positive externality effect, which can reduce the cost of production and transaction and improve productivity [71]. It is one of the key elements to promoting economic growth [80]. The further agglomeration of manufacturing and producer services provides additional possible advantages and forces for economic growth [22, 33, 35]. However, some studies have pointed out that agglomeration will produce a crowding effect, which negatively influences the environment and resources, and thus hinder economic growth [4]. Therefore, it is necessary to clarify the role of industrial agglomeration on economic growth in the background of comprehensive consideration of energy consumption and environmental pollution.

Green total factor productivity (GTFP) is a comprehensive index that can simultaneously reflect economic growth, energy consumption, and environmental pollution [52, 96]. In recent years, many studies

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have employed the GTFP to measure the quality of economic growth under consideration of energy and the environment [55, 90, 91]. Hence, this paper focuses on the GTFP. GTFP is usually affected by technological innovation, environmental regulation, and foreign investment [53, 60].

When studying the influence of IA on GTFP, the literature mostly stays at the level of provincial level or urban agglomeration [10, 37]. It lacks further analysis at the city level. Meanwhile, although some literature has compared the effects of specialized agglomeration and diversified agglomeration on traditional total factor productivity [3, 24, 39], they have not extended their research to GTFP. Hence, there are two main contributions of this paper. The first contribution is to make a horizontal comparison of the effects of different forms of IA, including manufacturing agglomeration, producer services agglomeration, and their collaborative agglomeration (COAG), on city's GTFP. It provides optional and diversified industrial development modes for the green growth of the city. Moreover, China's highly centralized political system has a profound impact on the order of distribution of factors of production in cities. Meanwhile, since China's industrial expansion is steadily relaxed from a planned economy to market-oriented, China's IA is intensely shaped by institutional elements. Therefore, the second contribution of this paper is analyzing the heterogeneous effects of IA on GTFP in China from the perspectives of development stages, administrative levels and policy differences.

For investigating the impression of various forms of IA on urban GTFP, this paper employs panel data from 281 prefecture-level cities in China from 2004 to 2017 for empirical analysis. The outcomes disclose that there is a considerable positive association between manufacturing agglomeration and urban GTFP, while producer services agglomeration has no significant effect. However, the COAG of manufacturing and producer services can notably improve GTFP. Meanwhile, for cities with institutional and policy advantages, COAG can play a more consequential green growth effect. But, for regular cities, manufacturing agglomeration is more valuable to advancing GTFP.

The rest of this paper is arranged as follows: the second part is a review of relevant literature; the third part is the theoretical analysis and research hypothesis; the fourth part describes the methods and data used; The fifth part is the empirical analysis of the results; the last part summarizes the main conclusions and puts forward corresponding policy suggestions.

Literature review

Total factor productivity (TFP) is an important index to quantify economic development [83, 103]. It generally refers to the ratio between the total output and the input of all factors of production. However, the traditional TFP only focuses on the saving of labor, capital, and other factors of production, but ignores the impacts of resource and environment [87]. As for GTFP, is an index that comprehensively considers economic growth, energy consumption, and pollution emissions [52, 101]. So, it can be used to objectively measure the quality of economic growth and guide the government to transform towards green development. About the measurement of China's GTFP, most of the literature is only at the provincial level [50] or urban agglomeration level [59, 86], or just use data of industry or firms [54, 66, 67]. For the study of the influencing elements of China's GTFP, scholars concentrate more on technological innovation, environmental regulation, and foreign investment [36, 53, 54, 60, 78, 84, 104, 109, 112], only a few studies focus on IA.

In fact, the question of how IA affects traditional economic growth has been discussed for many years, but the conclusion has not been unified so far. Some scholars believe that total factor productivity will be enhanced under the influence of IA because IA has positive economic externalities [8, 15, 16, 34]. On the other hand, some scholars believe that IA will produce negative economic externalities and significantly inhibit economic growth [5, 75]. Some studies found that the effect of IA on growth is nonlinear, and the direction of influence will fluctuate with the change of the degree of IA [5, 31]. Furthermore, it should be noticeable that when scholars conduct empirical tests on IA, they usually focus on industrial sectors [58, 65], especially in manufacturing [66, 67, 79, 92].

As the problems of environmental pollution and resource depletion continue to worsen, scholars begin to shift their research focus from traditional TFP to GTFP. Cheng and Jin [12] compared the supporting forces of specialized agglomeration and diversified agglomeration on GTFP at the provincial level in China. Chen et al. [10] revealed that polycentric agglomeration can notably foster the GTFP in provinces. Guo et al. [37] conducted a study on Northeast China and found that IA would have different impacts on the average green development efficiency in different periods. Yuan et al. [105, 106] pointed out that there is a substantial "positive U-shaped" relationship between China's manufacturing agglomeration and green growth efficiency. Xie et al. [98] and Li and Ma [57] have verified that financial agglomeration has direct and spillover effects on the GTFP of provinces and cities.

It can be found that although many articles have analyzed the relationship between IA and GTFP in China, they have the following defects: Firstly, most studies only stay at the level of provincial level or urban agglomeration. They lack further analysis on the level of prefecture-level cities. The agglomeration effect is a major advantage of cities. But, these studies are too macro to help the Chinese government implement the specific policy of green development in every city. Secondly, although some works of literature have accurately defined specialized agglomeration to a certain industry, there is no horizontal comparison between manufacturing and producer service agglomeration.

COAG among industries is a higher level of IA. The experience of the world's advanced economies also shows that the manufacturing industry needs the support and guidance of developed producer services in order to obtain high added value and strong competitiveness [22, 35]. Many domestic and foreign scholars have produced a lot of investigations on the effect of industrial COAG. With the development of the new economic geography theory, the early studies introduced producer services as intermediate goods into the theoretical model to explain its mechanism of action on manufacturing agglomeration and economic growth [29, 49, 70, 88]. Later, some studies show that the agglomeration of related industries is also characterized by Marshall–Arrow–Romer (MAR) externality and can promote regional economic development through scale economies effect and knowledge spillover effect [21, 27, 32, 45, 47, 77]. Vigorously developing advanced manufacturing and producer services and promoting industrial integration are strategic measures for China's green development transformation. However, there is little literature to analyze the influence of IA on GTFP from the perspective of COAG. Meanwhile, China's manufacturing industry shows a tendency to gather in coastal areas, while producer services have a low degree of agglomeration but bloom everywhere. Therefore, it is necessary to discuss the influence of the COAG of manufacturing and producer services on GTFP of Chinese cities.

Theoretical analysis and research hypotheses

The mainstream agglomeration theory believes that IA has MAR externality and can boost productivity [30, 49]. The mechanism of IA affecting urban GTFP can be mainly summarized into three aspects: the first is the effect of technological progress [51, 65]. Due to the competition among firms in the agglomeration area and the accumulation of professional knowledge and technical personnel in the region, the level of technological innovation will be improved [18, 111]. Technological advances can enhance the efficiency of factors of production, meaning lower resource input and energy consumption per unit of output. Thus, it can promote the improvement of GTFP. The second is the effect of optimal resources allocation [37]. Agglomeration brings spatial proximity and enables firms to share labor pools and intermediate product markets. It can diminish the cost and enhance the efficiency of labor matching and intermediate product transportation. Optimized resource allocation can increase GTFP. The third is to reduce emissions of pollution [7, 58]. Firms in the agglomeration area can share infrastructure and pollution treatment equipment. It not only avoids the flood of low-level repetitive construction and the long-distance call of large-scale resources and energy, but also realizes the centralized treatment of pollution. Thus, the generation and diffusion of environmental pollution can be both reduced. The drop of pollutant emissions can lead to the growth of GTFP. However, combined with the actual characteristics of China's industrial development, the agglomeration effect of manufacturing and producer services may have different impacts on GTFP.

From the angle of manufacturing, China has become a manufacturing giant in the world. The added value of the world's manufacturing factories reached 31.4 trillion yuan in 2021 [13]. Therefore, the economies of scale brought by manufacturing agglomeration are obvious [38, 85]. Some scholars state that the economies of scale enable shared infrastructure to increase utilization and reduce cost of pollution control, which is beneficial to environmental pollution control [24, 44]. However, other studies suggest that the scale production would increase energy consumption and pollution emissions at the same time [81]. It is known that China's manufacturing industry is at the medium and low end of the global industrial chain and relies more on resources, environment, and human input. But it has been transforming to green development since the 18th National Congress of the Communist Party of China in 2012. Therefore, this paper puts forward the first hypothesis:

H1: The agglomeration of the manufacturing industry is beneficial to the enhancement of GTFP in Chinese cities.

From the perspective of producer services, spatial agglomeration of producer services can foster endogenous economic growth through scale economies effect and knowledge spillover effect of intermediate inputs [17, 88]. Meanwhile, because of its knowledge-intensive and technology-intensive characteristics, the agglomeration of producer services can promote technological progress, enhance labor productivity, and decrease unit energy intensity and pollution emissions [46].

However, although the development of producer services in China is accelerating, lacking of effective regional division of labor in producer services will lead to excessive competition and waste of resources [69, 117]. A low level of repetitive construction will greatly alter the effectiveness of resource allocation, thus affecting green growth. As a result, the second hypothesis is proposed:

H2: The agglomeration of producer services is not helpful to the enhancement of GTFP in Chinese cities.

From the perspective of COAG of manufacturing and producer services, on the one hand, manufacturing agglomeration creates market demands for intermediate products. The larger the scale of the manufacturing industry is, the greater the demand for intermediate products will be, and the market of producer services supporting it will gradually expand and form a scale. On the other side, the agglomeration of producer services generates more kinds of intermediate products and triggers the development of the manufacturing industry through the continuous output of human capital and knowledge capital [1, 28, 35]. Therefore, the COAG of manufacturing and producer services can not only act on urban GTFP through technological progress effect, optimal allocation effect, and emission reduction effect just like single industry agglomeration, but also magnifies the effect of economic externalities through mutual promotion and circular accumulation effect among industries. However, since most of China's manufacturing agglomeration is distributed in the eastern coastal cities, while producer services are evenly distributed, the COAG effect of the two industries will be various in different cities in China. Hence, the third hypothesis of this paper is proposed:

H3: The COAG of manufacturing and producer services will support the growth of GTFP in Chinese cities, but the effect is heterogeneous.

Methods and data

Model derivation

Based on Ciccone [15], this paper discovers the connection between IA and GTFP by referring to the methods of Lin and Tan [61]. The specific model is derived as follows.

Suppose a country has n regions of different sizes, and the output per unit area within each region is y. In general, the production function is assumed to follow the form of the Cobb–Douglas function. Meanwhile, according to the empirical analysis experience, it is assumed that the elasticity of output per unit area relative to regional production density is constant. Therefore, the production function of output y per unit area in this region can be defined as:

$$y = \Omega f(l, k, e, Y, A) = \Omega\left(l^{\alpha} k^{\beta} e^{1-\alpha-\beta}\right)^{\rho}\left(\frac{Y}{A}\right)^{\frac{\lambda-1}{\lambda}}, \tag{1}$$

where Ω refers to the GTFP to be studied in this paper. l is the labor force per unit area; k is physical capital per unit area; e is energy consumption per unit area; Y is total output; A is the area of land in the region. α and β are constants between 0 and 1, which measure the share of labor and capital; $0 < \rho < 1$ which describes the return on labor, capital, and energy within the region; $\lambda > 1$, means that production has externalities.

Further, it is assumed that labor, capital, and energy are equally distributed over land in each region, so the total output Y of each region can be defined as:

$$Y = yA = \Omega\left(l^{\alpha} k^{\beta} e^{1-\alpha-\beta}\right)^{\rho}\left(\frac{Y}{A}\right)^{\frac{\lambda-1}{\lambda}} A = \Omega\left[\left(\frac{L}{A}\right)^{\alpha}\left(\frac{K}{A}\right)^{\beta}\left(\frac{E}{A}\right)^{1-\alpha-\beta}\right]^{\rho}\left(\frac{Y}{A}\right)^{\frac{\lambda-1}{\lambda}} A, \tag{2}$$

where L is the total number of employed people in the region; K is the total physical capital of the region; and E is the total energy consumption in the region.

According to formula (2), the output of unit labor input is:

$$\frac{Y}{L} = \Omega^{\lambda}\left(\frac{K}{L}\right)^{\beta\rho\lambda}\left(\frac{E}{L}\right)^{(1-\alpha-\beta)\rho\lambda}\left(\frac{L}{A}\right)^{\rho\lambda-1}. \tag{3}$$

Then, set the price of capital as r and the price of energy as p. Since the marginal output of each factor of production is equal to its price, K and E can be defined as $K = \frac{\beta\rho Y}{r}$, $E = \frac{(1-\alpha-\beta)\rho Y}{p}$. Substituting them into formula (3) then we have:

$$\frac{Y}{L} = \Omega^{\frac{\lambda}{1-\rho\lambda(1-\alpha)}}\left(\frac{\beta\rho}{r}\right)^{\frac{\beta\rho\lambda}{1-\rho\lambda(1-\alpha)}}\left[\frac{(1-\alpha-\beta)\rho}{p}\right]^{\frac{(1-\alpha-\beta)\rho\lambda}{1-\rho\lambda(1-\alpha)}}\left(\frac{L}{A}\right)^{\frac{\rho\lambda-1}{1-\rho\lambda(1-\alpha)}}. \tag{4}$$

If let $\theta = 1-\rho\lambda(1-\alpha)$, $C = \left(\frac{\beta\rho}{r}\right)^{\frac{\beta\rho\lambda}{1-\rho\lambda(1-\alpha)}}\left[\frac{(1-\alpha-\beta)\rho}{p}\right]^{\frac{(1-\alpha-\beta)\rho\lambda}{1-\rho\lambda(1-\alpha)}}$ and $\eta = \frac{\rho\lambda-1}{1-\rho\lambda(1-\alpha)}$, then formula (4) can be written as:

$$\frac{Y}{L} = \Omega^{\theta} C \left(\frac{L}{A} \right)^{\eta}, \tag{5}$$

$$\Omega = C^{-\frac{1}{\theta}} \left(\frac{L}{A} \right)^{-\frac{\eta}{\theta}} \left(\frac{Y}{L} \right)^{\frac{1}{\theta}}, \tag{6}$$

where θ, C and η are constants. It can be perceived from Eq. (6) that GTFP is affected by labor input and output per unit of the labor force in a unit area. $\frac{L}{A}$ is the labor input per unit area, which is also the main explanatory variable, because IA can be expressed as the concentration of employees in an industry in a certain region.

Baseline regression model

Based on the above derivation and considering that the sample data is a short panel data, the fixed-effect model is preferred in this paper. The specific formula is as follows:

$$\mathrm{GML_{it}} = \alpha + \beta \mathrm{IA}_{it} + \lambda \sum X_{it} + u_i + \gamma_t + \varepsilon_{it}, \tag{7}$$

where GML is the calculated index of GTFP, which is the explained variable; IA is the main explanatory variables, including manufacturing agglomeration and producer services agglomeration and their COAG; X_{it} is a group of control variables, including population density, industrial structure, government support, foreign investment, and environmental regulation; u_{i} is the city fixed effect; γ_{t} is the time fixed effect; $\varepsilon_{\mathrm{it}}$ is the random perturbation term.

Measurement of green total factor productivity

GTFP is chosen to quantify the development of the green economy in China. Because GTFP is a comprehensive index that takes economic growth, resource conservation, and environmental protection into full consideration, and it can describe green growth more accurately. Most of the latest literature utilizes the Super-slack-based measure (Super-SBM) model with undesirable outputs and a Global Malmquist–Luenberger (GML) index to measure GTFP [68, 104]. Furthermore, the GML index can be decomposed into efficiency change (EC) and technology change (TC) [72]. The specific formula is as follows:

$$\mathrm{GML}^{(t-1,t)} = \mathrm{EC}^{(t-1,t)} \times \mathrm{TC}^{(t-1,t)}. \tag{8}$$

The EC is the relative efficiency change index under the condition of constant return to scale and free disposal of elements, while the TC refers to technological progress and innovation [25, 100]. EC > 1 indicates that the technical efficiency has been improved, otherwise, it means decline. TC > 1 means there is progress in production technology and vice versa.

In order to obtain the GTFP of Chinese cities, this paper not only considers the input of labor, capital, and energy but also includes the expected and unexpected outputs. Specific indicators are selected as follows:

(1) Labor input: the number of employed people in prefecture-level cities;
(2) Capital input: owing to the lack of data on capital stock, this paper uses the data of fixed asset investment in prefecture-level cities and adopts the "perpetual inventory method" to calculate by referring to the practice of Meng and Qu [72]. Specifically, it takes the year 2000 as the base period for the price adjustment, and sets the capital depreciation rate as 9.6%;
(3) Energy consumption: owing to the lack of energy consumption data of prefecture-level cities, this paper uses the electricity consumption data of prefecture-level cities as energy consumption by referring to the method of Lin [62];
(4) Expected output: real GDP (taking 2000 as the base year);
(5) Undesired output: in recent years, the government and the public have not only paid attention to the emission of industrial pollution, but also been sensitive to the environmental air quality caused by air pollution. Therefore, in addition to using the industrial wastewater emissions, industrial sulfur dioxide emissions, and industrial soot emissions of prefecture-level cities as bad outputs [72, 105, 106], this paper also uses PM2.5 data.

Finally, the MaxDEA Ultra 8 software is used to obtain the final calculation results. As shown in Fig. 1, the mean value of GML of Chinese cities fluctuates horizontally around the value of 1, and the variation trend of TC is almost consistent with it. The fluctuation trend of EC also keeps around the value of 1, but its fluctuation direction is just opposite to that of GML. According to formula (8), when the value of EC or TC is greater than 1, EC or TC can be considered to contribute to GML; when EC or TC is equal to 1, no effect is generated; when EC or TC is less than 1, it is considered that EC or TC limits GML. Therefore, this paper preliminarily concludes that the growth of GTFP in Chinese cities essentially comes from technological change.

Industrial agglomeration

IA describes the concentration of an industry in the same place. Since employment density is an absolute indicator, scholars are more inclined to choose the

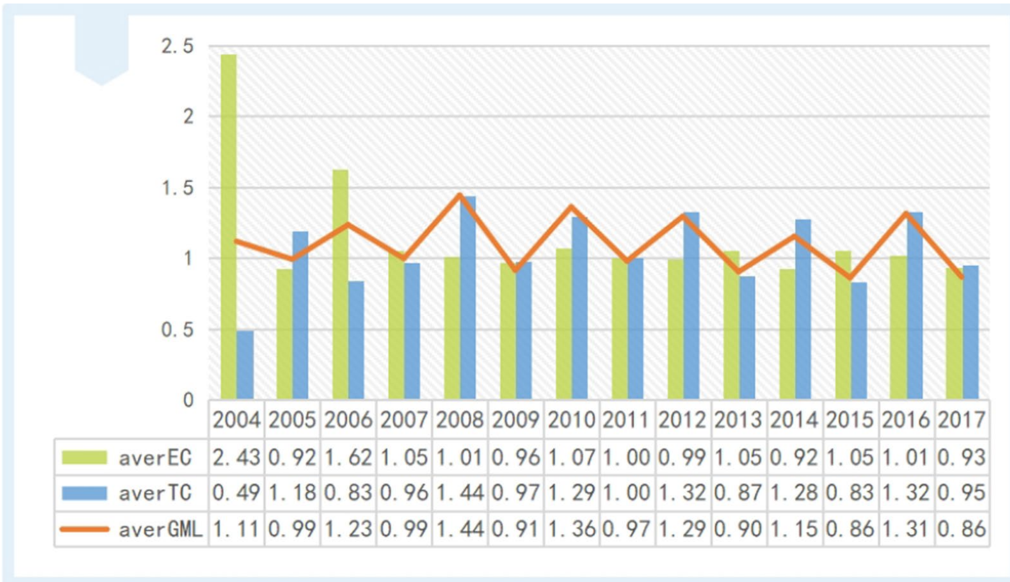

Fig. 1 The mean change trends of GML, EC, and TC in Chinese cities

Herfindahl–Hirschman index [95], location entropy [114], Ellison–Glaeser index [21, 63] and spatial Gini index to measure IA. Finally, this paper employs the location entropy index to measure the agglomeration degree of manufacturing and producer services at the prefecture-level city level. The specific calculation formula is as follows:

$$\mathrm{LQ}_{ij} = \frac{x_i/X_j}{\sum x_i/\sum X_j}, \tag{9}$$

where x_i is the number of employees in an industry i in region j; X_j is the employment of all industries in region j; $\sum x_\mathrm{i}$ is the number of people employed in an industry i in all regions; $\sum X_\mathrm{j}$ is the number of people employed in all industries in all regions. LQ_ij represents the agglomeration index of the i industry in region j. The larger the value is, the higher the degree of agglomeration or stronger specialization of the i industry in this region. When $\mathrm{LQ}_\mathrm{ij} > 1$, it can be said that the i industry in this region has an advantage over the whole country. Manufacturing industry agglomeration is represented by LQ_Man in this paper, while producer service industry agglomeration is represented by LQ_PS8. In addition, referring to the classification of service industry in the "National Standard for Industry Classification", this paper takes information, transportation, finance, real estate, leasing, science, residential services, and education as the representatives of producer services [102].

It can be noted from Fig. 2 that the spatial distribution changes of manufacturing agglomeration and producer services agglomeration. The majority of the cities with manufacturing advantages are located in the coastal areas of eastern China, and increasingly cluster in the Beijing–Tianjin–Hebei region, the Yangtze River Delta, the Pearl River Delta, and the Central Plains. And, the distribution pattern of cities with the advantage of producer services in the whole country changed from uniform distribution to distribution around the manufacturing industry.

In fact, the COAG of manufacturing and producer services is the manifestation of industrial interaction and deepening of the division of labor, ultimately for the reduction of transportation cost and the enhancement of productivity. Referring to the practice of Zhang et al. [110], Zeng et al. [108], and Lin et al. [64], the relative difference of location entropy is used to characterize the COAG of manufacturing and producer services. COAG is defined as:

$$\mathrm{COAG} = 1 - \frac{|\mathrm{LQ}_{\mathrm{Man}} - \mathrm{LQ}_{\mathrm{PS8}}|}{\mathrm{LQ}_{\mathrm{Man}} + \mathrm{LQ}_{\mathrm{PS8}}} + \mathrm{LQ}_{\mathrm{Man}} + \mathrm{LQ}_{\mathrm{PS8}}, \tag{10}$$

where $\mathrm{LQ}_{\mathrm{Man}}$ is the location entropy of the manufacturing industry; LQ_{PS8} is the location entropy of producer services. COAG represents the degree of collaborative agglomeration of manufacturing and producer services, and the larger the value is, the higher the collaborative degree of the two industries is.

Figure 3 shows the spatial distribution of COAG. The darker the green area, the higher the degree of COAG of manufacturing and producer services. It can be seen that cities with a high degree of COAG in China have changed from mostly distributed in eastern coastal areas to urban

Fig. 2 Spatial distribution of manufacturing agglomeration (LQ_MAN) and producer services agglomeration (LQ_PS8)

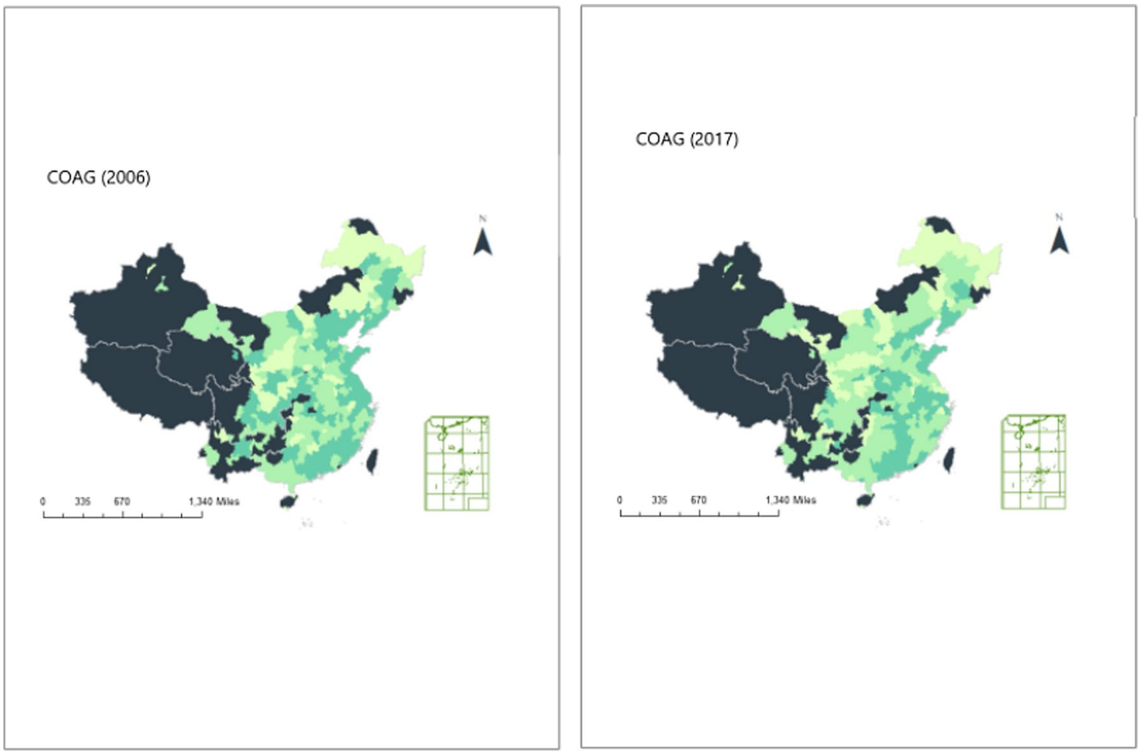

Fig. 3 Spatial distribution of collaborative agglomeration (COAG) of manufacturing and producer services

agglomerations dominated by Beijing–Tianjin–Hebei, Yangtze River Delta, Pearl River Delta, middle Reaches of Yangtze River, and Central Plains.

Control variables

In addition to the main explanatory variables, other factors affecting GTFP are also considered in this paper:

(1) Population density (PopDensity): it is represented by population per square kilometer. Population growth, while expanding the labor pool in the local market, also increases the demand for resources and energy [105, 106].
(2) Industrial structure (TaddSadd): use the ratio of the added value of tertiary industries to the added value of secondary industries instead. The higher the proportion of tertiary industry means that the industry is shifting from primary and secondary industry to tertiary industry, which is the performance of the upgrading of industrial structure. The upgraded industrial structure will be beneficial to the enhancement of GTFP [118].
(3) Environmental regulation (Regulation): the entropy method is used to calculate the emissions of industrial wastewater, industrial sulfur dioxide, industrial soot, and PM2.5, and finally a comprehensive index is obtained. The higher the value, the more severe the environmental regulation and the fewer pollution emissions. Environmental regulation is a key factor to promote green development transformation, and much literature has proved its impact on green technology innovation and energy use efficiency, but the conclusions are not unified [20, 113, 115].
(4) Government support (SciEdu): measured by spending on science education as a share of fiscal spending. When the government transfers its financial support to science and education, it will contribute to the improvement of urban human capital and the increase of scientific innovation, thus leading to the effective enhancement of GTFP [56]. However, other studies have shown that government support can inhibit the improvement of technical efficiency [97].
(5) Foreign investment (uF): it is expressed by the proportion of actually used foreign investment in

Table 1 Descriptive statistics of variables

Variable	Obs	Mean	Std. Dev.	Min.	Max.
lnGML	3934	0.058	0.285	− 3.655	2.334
lnLQ_MAN	3934	− 0.313	0.627	− 3.891	1.082
lnLQ_PS8	3934	− 0.076	0.295	− 1.677	1.179
lnCOAG	3934	0.910	0.212	− 0.027	1.282
lnPopDensity	3934	5.689	1.036	0	7.887
lnTaddSadd	3934	− 0.229	0.444	− 2.362	1.562
lnRegulation	3934	− 1.511	0.093	− 1.900	− 1.339
lnSciEdu	3934	− 1.653	0.274	− 5.197	0
lnuF	3934	0.923	1.388	− 7.953	3.889

GDP. Some scholars confirmed the Pollution Haven Hypothesis and believed that foreign investment would hinder local green development [107]. Other scholars argue that foreign investment has a technology spillover effect and can improve the level of development [40].

Sources of data
By reason of the serious lack of data of some cities, this paper finally takes 281 out of 294 prefecture-level cities in China as the research object. The data are principally obtained from The Statistical Yearbook of Chinese Cities and Statistical yearbooks of each prefecture-level city from 2004 to 2017 [73]. For some missing data, the linear interpolation method is used. To reduce heteroscedasticity, logarithmic changes were made to all variables before regression. Table 1 shows descriptive statistics for all variables.

Empirical analysis
Prior examination
Before the baseline regression analysis, the variance inflation factor (VIF) test was carried out for each variable first. Since the maximum VIF is 1.67, there is no need to worry about multicollinearity. It was observed that most of the individual dummy variables were significant by the LSDV method, so it is believed that there is an individual effect. The fixed-effect model should be selected by

Table 2 Baseline regression result

Variables	(1)	(2)	(3)	(4)	(5)	(6)
lnLQ_MAN	0.046**	0.042*				
	(2.12)	(1.84)				
lnLQ_PS8			0.058	0.079		
			(0.83)	(1.18)		
lnCOAG					0.148*	0.151*
					(1.94)	(1.94)
lnPopDensity		− 0.009		− 0.008		− 0.009
		(− 1.06)		(− 1.00)		(− 1.02)
lnTaddSadd		− 0.062***		− 0.074***		− 0.065***
		(− 2.72)		(− 3.75)		(− 2.94)
lnRegulation		0.720***		0.731***		0.729***
		(6.24)		(6.33)		(6.32)
lnSciEdu		− 0.045**		− 0.047***		− 0.044**
		(− 2.58)		(− 2.64)		(− 2.54)
lnuF		− 0.004		− 0.004		− 0.004
		(− 1.00)		(− 1.06)		(− 1.01)
Constant	0.078***	1.130***	0.070***	1.132***	− 0.073	0.989***
	(4.25)	(6.28)	(3.96)	(6.33)	(− 0.86)	(5.07)
Observations	3934	3934	3934	3934	3934	3934
R-squared	0.391	0.398	0.390	0.399	0.392	0.399
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Number of cities	281	281	281	281	281	281

Robust t-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

the Hausman test. Meanwhile, the joint significance test for all dummy variables of years strongly rejects the null hypothesis of no time effect. This proves that it is correct to estimate the influence of IA on GTFP by using the bidirectional fixed-effect model of panel data.

Baseline regression result

Table 2 displays the results of the baseline regression for the full sample. Columns (1), (3), and (5) are reference frames without control variables. As can be seen from columns (2), (4), and (6), the results remain consistent after a series of control variables are added. Column (2) shows that every 1% increase in manufacturing agglomeration will significantly lead to a 0.042% increase in urban GTFP. This result confirms hypothesis 1 of this paper. Indeed, China is a country dominated by manufacturing. Made in China 2025 also emphasizes that promoting the expansion of the manufacturing industry is the key to improving the quality and efficiency of the economy. Therefore, manufacturing agglomeration is advantageous to the transformation of Chinese cities to green development. The results shown in column (4) are consistent with hypothesis 2 of this paper, that is, although the coefficient of agglomeration of producer services is positive, its promoting effect is not significant. This seems to indicate that the agglomeration of producer services in Chinese cities has not been able to effectively play the agglomeration effect brought by its knowledge-intensive and high added value while expanding its scale. According to the coefficients in column (6), there is a considerable positive correlation between the COAG formed by manufacturing and producer services and the GTFP of the city. Specifically, at the confidence level of 10%, when the coefficient of COAG increases by 1%, GTFP will increase by 0.151%. It can be realized that although the agglomeration of producer services alone cannot effectively promote the improvement of GTFP, it can significantly drive the growth of GTFP when producer services are integrated with manufacturing to form a COAG pattern. This result confirms the inference of hypothesis 3 in this paper that COAG among industries can amplify the effect of economic externalities and realize the green transformation of development.

Next, we briefly analyze the results of the control variables. Firstly, we observe that the coefficient of lnPopDensity is always negative. This result confirms the previous analysis that the increase of population density will enlarge the demand for resources and energy to a certain extent. But because the results are insignificant, they are not statistically significant. Secondly, the coefficient of lnTaddSadd is considerably negative, which means that industrial structure upgrading inhibits the growth of GTFP. It is inconsistent with the conclusion of Zhu et al. [118]. This may be because most cities expand the service industry in the same mode and the government makes improving the output of the service sector a mandatory indicator [11]. In this context, the expansion of the service industry cannot promote the green transformation of the economy, but will seriously hinder the efficiency of resource allocation [61]. Thirdly, according to the correlation coefficient of lnRegulation, at the confidence level of 1%, every 1% increase in environmental regulation intensity can promote the growth of urban GTFP by about 0.7%. Therefore, for China, environmental regulation is an indispensable tool to promote green development. Fourthly, from the correlation coefficient of lnSciEdu, it can be found that the transfer of government financial expenditure to science and education will reduce the GTFP of cities. This is similar to the findings of Xiao and Lin [97]. Finally, since the coefficient of lnuF is negative but not statistically significant, this paper can conclude that foreign direct investment has no impact on urban green development.

Impacts on the efficiency change (EC) and technology change (TC)

Table 3 reports the effects of various types of IA on the efficiency change (EC) and technology change (TC). According to the results of columns (1) and (2), manufacturing agglomeration has a significant positive connection with technological change (TC), but no substantial positive connection with efficiency change (EC). At the confidence level of 1%, every 1% increase in urban manufacturing concentration can lead to 0.03% technological progress. This shows that at present, China's manufacturing industry agglomeration has indeed brought about continuous internal technological progress and is developing towards a technology-oriented direction. However, the agglomeration of the manufacturing industry failed to bring effective improvement of actual technical efficiency, which may be caused by the invalid transformation of patent achievements. A large number of patents have been created, but failed to play their due value and role. It means that scientific and technological achievements have failed to become the pushing force of economic development and create economic benefits. Therefore, manufacturing agglomeration cannot effectively improve the efficiency of technology.

As can be seen from columns (3) and (4), agglomeration of producer services can improve technical efficiency, but diminish the level of production technology at the same time. This opposite force leads to the failure of the agglomeration of service industries to achieve GTFP growth. This may be explained by the fact that producer services in China currently mainly play the role of cost-saving and efficiency improvement, but the subjective

Table 3 Effects of various types of industrial agglomeration (IA) on EC and TC

Variables	(1) EC	(2) TC	(3) EC	(4) TC	(5) EC	(6) TC
lnLQ_MAN	0.012	0.030***				
	(0.51)	(2.95)				
lnLQ_PS8			0.148**	− 0.069***		
			(2.08)	(− 3.06)		
lnCOAG					0.113	0.037
					(1.33)	(1.29)
lnPopDensity	− 0.009	− 0.000	− 0.008	− 0.001	− 0.009	− 0.000
	(− 0.76)	(− 0.03)	(− 0.68)	(− 0.06)	(− 0.74)	(− 0.01)
lnTaddSadd	− 0.045*	− 0.017	− 0.061***	− 0.012	− 0.046*	− 0.019
	(− 1.85)	(− 1.45)	(− 2.88)	(− 1.04)	(− 1.92)	(− 1.65)
lnRegulation	0.905***	− 0.185*	0.931***	− 0.200*	0.913***	− 0.184*
	(6.18)	(− 1.75)	(6.38)	(− 1.88)	(6.21)	(− 1.73)
lnSciEdu	0.012	− 0.057***	0.010	− 0.057***	0.013	− 0.057***
	(0.49)	(− 2.96)	(0.39)	(− 2.99)	(0.53)	(− 2.97)
lnuF	− 0.003	− 0.001	− 0.003	− 0.001	− 0.003	− 0.001
	(− 0.56)	(− 0.39)	(− 0.66)	(− 0.34)	(− 0.55)	(− 0.40)
Constant	2.255***	− 1.125***	2.289***	− 1.157***	2.158***	− 1.169***
	(9.81)	(− 6.60)	(10.07)	(− 6.79)	(8.95)	(− 6.79)
Observations	3934	3934	3934	3934	3934	3934
R-squared	0.463	0.616	0.466	0.617	0.464	0.616
Number of cities	281	281	281	281	281	281

Robust t-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

initiative of innovation is poor. Hence, it can significantly encourage the growth of technical efficiency, but inhibit technological progress.

The results in Table 2 have verified that the COAG of manufacturing and producer services is a new direction to promote the construction of manufacturing power and high-quality development. However, the results in Columns (5) and (6) of Table 3 disclose that the correlation coefficient between the COAG and EC and TC is positive but not significant. There are two possible reasons. Firstly, the development mode and industry layout of producer services in various cities are seriously formalized. The supply of the service industry fails to match the deep demand of the manufacturing industry effectively, thus leading to a significant reduction in the promotion effect of COAG between industries on production efficiency. Secondly, as producer services are still mainly supporting the expansion of the manufacturing industry, they lack the ability to lead the manufacturing industry in incubating new products, developing new technologies, and cultivating new industries. Therefore, although the current COAG can bring the growing of GTFP, on the whole, it still cannot significantly stimulate the improvement of efficiency and technological progress, respectively.

Endogenous problem

In general, the use of system GMM estimation for dynamic panels is one of the solutions to the endogenous problem. It solves the endogenous problem effectively by using the lag value of endogenous variables as instrumental variables. Therefore, considering that the current GTFP may be affected by the past situation, this paper further introduces the first-order lag term of the explained variable to form the dynamic panel data [5] and uses the system GMM to estimate it. The regression results are showed in Table 4. Specifically, a prerequisite for using the system GMM is that the disturbance term is not autocorrelated. The Arellano–Bond test is used to verify whether the error term has a sequence correlation problem, and the results all show that the difference of disturbance term has first-order autocorrelation but no second-order or higher-order autocorrelation. In addition, another condition for using the system GMM is to pass the over-identification test. The results of the

Table 4 Regression results of system GMM

Variables	(1) SysGMM	(2) SysGMM	(3) SysGMM
L.lnGML	− 0.252***	− 0.250***	− 0.255***
	(− 7.05)	(− 7.16)	(− 7.26)
lnLQ_MAN	0.046***		
	(3.33)		
lnLQ_PS8		0.047	
		(1.37)	
lnCOAG			0.168***
			(3.64)
lnPopDensity	− 0.005	− 0.001	− 0.005
	(− 0.73)	(− 0.16)	(− 0.66)
lnTaddSadd	− 0.037	− 0.060**	− 0.057*
	(− 1.47)	(− 2.22)	(− 1.94)
lnRegulation	0.187***	0.130**	0.223***
	(2.66)	(2.18)	(3.30)
lnSciEdu	− 0.037*	− 0.041**	− 0.031
	(− 1.77)	(− 2.09)	(− 1.57)
lnuF	− 0.004	0.002	− 0.003
	(− 0.85)	(0.60)	(− 0.77)
Constant	0.134	0.002	0.026
	(1.24)	(0.02)	(0.27)
Observations	3653	3653	3653
Number of cities	281	281	281
AR(1)	0.000	0.000	0.000
AR(2)	0.336	0.323	0.347
Hansen test	0.201	0.326	0.258
Wald	3026	3123	2965

z-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

Hansen test show that the null hypothesis of "all instrumental variables are valid" can be accepted at the significance level of 5%. Therefore, this paper can use the system GMM to solve the endogenous problem.

Furthermore, referring to Xu et al. [99], the average value of various industrial agglomeration in the province is calculated and used as an instrumental variable. Table 5 reports regression results of using the 2SLS estimators. The first-stage regression results show that all the instrumental variables used positively affect the endogenous explanatory variables at the confidence level of 1%. Combined with the results of unrecognizable test and weak instrumental variable test, we believe that the selected instrumental variable is effective. The results of the second-stage regression report were consistent with the baseline estimates. It proves that the results remain robust and reliable after mitigating endogeneity problems.

Robustness test

In order to confirm the reliability of the effect of various IA on GTFP, some robustness tests are supplemented. Firstly, columns (1) to (3) in Table 6 excluded Beijing, Tianjin, Shanghai, and Chongqing from the sample, and performed regression on the data of the remaining 277 cities. Then, referring to the practice of Yuan et al. [105, 106] resource-based cities were removed from the sample after considering the impact of resource conditions on manufacturing agglomeration. Consistent with the National Sustainable Development Plan for Resource-Based Cities (2013–2020) issued by The State Council of China, there are 126 resource-based prefecture-level cities in China, including four types: growth, maturity, decline, and regeneration. Among them, maturity resource-based cities have been in the stage of stable resource development, so those cities are most affected by all kinds of resource endowment. Therefore, columns (4) to (6) excluded 23 maturity resource-based cities, so as to avoid the impact of resource advantages. The results prove that the key conclusions of this paper are credible, that is, both manufacturing agglomeration and COAG can notably stimulate the growth of urban GTFP.

Further analysis

In the past, most literature carried out heterogeneity analysis on Chinese samples from the perspectives of eastern, central, and western regions, because the economic development gap of these three regions in China was quite obvious. However, in the literature review, this paper found that China's institutional and policy factors have a substantial power on IA and GTFP. Therefore, this paper discovers the connection between IA and urban GTFP from the perspective of institutional and policy heterogeneity.

The administrative level of Chinese cities

The impact of administrative level difference between Chinese cities on IA and economic growth cannot be ignored. High-level cities are usually favored by the central government and have priority in the allocation of important resources or production factors (such as capital, human capital, infrastructure investment, advanced technology, and preferential policies), and then realize further agglomeration and economic development with more resources [19, 43, 116]. The administrative level determines the existing development environment and agglomeration level of a city. Therefore, heterogeneity analysis based on the administrative level of a city is conducive to finding more targeted green industrial development policies. From top to bottom, Chinese cities are divided into municipalities directly under the central Government, vice-provincial cities, non-vice-provincial

Table 5 IV + 2SLS

Variables	(1) First-stage lnLQ_MAN	(2) Second-stage lnGML	(3) First-stage lnLQ_PS8	(4) Second-stage lnGML	(5) First-stage lnCOAG	(6) Second-stage lnGML
avlnLQ_MAN	1.010***					
	(29.88)					
lnLQ_MAN		0.107***				
		(2.76)				
avlnLQ_PS8			1.016***			
			(24.39)			
lnLQ_PS8				0.033		
				(0.32)		
avlnCOAG					1.004***	
					(22.35)	
lnCOAG						0.267*
						(1.91)
Observations	3934	3934	3934	3934	3934	3934
R-squared		0.396		0.398		0.398
Number of cities	281	281	281	281	281	281
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Under-identification test		0.000		0.000		0.000
Weak identification test		892.645		594.703		499.593

Robust t-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

capital cities, and ordinary prefecture-level cities. In this paper, municipalities directly under the central government, vice-provincial cities, and non-vice-provincial capital cities are uniformly defined as the prefecture-level cities of high administrative level (High-level), with a total of 35 cities. The remaining 246 prefecture-level cities are lower-level cities. Table 7 reports the results of the heterogeneity analysis based on the administrative level of the city. According to the coefficient, for high-level cities, the COAG of manufacturing and producer services can significantly increase GTFP. For low-level cities, COAG can also promote their GTFP, but the correlation coefficient and significance are much lower than that of high-level cities. It means that the collaborative development of manufacturing and producer services in high-level cities is better than that in low-level cities. In addition, the results indicate that manufacturing agglomeration has no significant promotion effect in high-level cities, but it plays a substantial part in low-level cities. This seems to prove the importance of developing the manufacturing industry for low-level cities to go green.

Urban agglomeration

Cities within urban agglomeration can not only optimize resource allocation and generate huge agglomeration economic benefits through spatial close interaction, but also have innate policy support [94]. China's State Council [14] has not only defined the main role of urban agglomeration in promoting the country's new-type urbanization, but also approved nine state-level urban agglomerations. Therefore, compared with cities outside urban agglomeration, they have more development conditions and advantages. In addition, when drawing the spatial distribution map of IA, it is found the consistency between an industrial distribution and urban agglomeration distribution. Therefore, it is crucial to study the heterogeneity of samples from urban agglomerations and non-urban agglomerations. This paper classifies 155 prefecture-level cities in 11 urban agglomerations (including Beijing–Tianjin–Hebei Urban Agglomeration, Yangtze River Delta Urban Agglomeration, Pearl River Delta Urban Agglomeration, Urban Agglomeration of Triangle of Central China, Harbin–Changchun Urban Agglomeration, Chengdu–Chongqing Urban

Table 6 Results of robustness test

Variables	(1)	(2)	(3)	(4)	(5)	(6)
lnLQ_MAN	0.043*			0.043*		
	(1.90)			(1.70)		
lnLQ_PS8		0.080			0.084	
		(1.17)			(1.11)	
lnCOAG			0.154**			0.155*
			(1.98)			(1.73)
lnPopDensity	− 0.009	− 0.009	− 0.009	− 0.012	− 0.011	− 0.012
	(− 1.10)	(− 1.03)	(− 1.06)	(− 1.23)	(− 1.18)	(− 1.20)
lnTaddSadd	− 0.062***	− 0.073***	− 0.065***	− 0.069***	− 0.080***	− 0.071***
	(− 2.68)	(− 3.68)	(− 2.89)	(− 2.72)	(− 3.73)	(− 2.86)
lnRegulation	0.680***	0.696***	0.691***	0.786***	0.797***	0.793***
	(6.05)	(6.14)	(6.14)	(6.64)	(6.70)	(6.71)
lnSciEdu	− 0.045**	− 0.047***	− 0.045**	− 0.035*	− 0.040**	− 0.035*
	(− 2.58)	(− 2.64)	(− 2.54)	(− 1.87)	(− 2.04)	(− 1.87)
lnuF	− 0.004	− 0.005	− 0.004	− 0.006	− 0.006	− 0.006
	(− 1.09)	.(− 1.14)	(− 1.10)	(− 1.42)	(− 1.48)	(− 1.39)
Constant	1.074***	1.081***	0.932***	1.263***	1.257***	1.113***
	(6.09)	(6.14)	(4.86)	(6.82)	(6.80)	(5.39)
Observations	3878	3878	3878	3612	3612	3612
R-squared	0.399	0.399	0.400	0.410	0.410	0.411
Number of cities	277	277	277	258	258	258

Robust t-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

Agglomeration, Central Plains Urban Agglomeration, Beibu Gulf Urban Agglomeration, Guanzhong Plains Urban Agglomeration, Huhehaote–Baotou–Eerduosi–Yulin Urban Agglomeration, and Lanzhou–Xining Urban Agglomeration) as inner cities of urban agglomerations, while the rest are outer cities. As can be observed from the results in Table 8, only COAG within urban agglomeration plays a significant role in improving GTFP. At the confidence level of 5%, the GTFP of the city will increase by 0.115% for every 1% increase in the degree of COAG.

Different stages of development

China is a country with a government-led market economy, so the leading policies will change with the evolution of the development stage. Since China joined the WTO in 2001, its economy has developed at a faster pace. From 2003 to 2007, the Chinese government strengthened macro-control because of concerns about overheating. In 2008, the outbreak of the international financial crisis hit China's economy partly. Therefore, 2012 is an important turning point, before which China's economy was in a stage of constant adjustment. After the 18th National Congress of the Communist Party of China in 2012, China's economy entered a new stage of development, and the transformation and upgrading of its economic structure entered a critical period. It has not only put forward policies to guide industrial development and upgrading, such as Made in China 2025 and The Guiding Opinions of The State Council on Accelerating the Development of Producer Services to Promote the Adjustment and Upgrading of Industrial Structure, but also put forward the development concept of innovative, coordination, green, open and shared at the Fifth Plenary Session of the 18th CPC Central Committee. Therefore, this paper divides the sample into two periods: the period from 2004 to 2011 is the adjustment stage, and the period from 2012 to 2017 is the new development stage with green and sustainable development as the goal. It can be seen from Table 9 that IA in the adjustment stage has not performed a good role in stimulating green growth. After entering the new stage, the COAG of manufacturing and producer services drastically rises the GTFP of cities at the confidence level of 10%. It seems to state that the Chinese government's series of policy guidance for economic green transformation has significant effects.

Table 7 Heterogeneity analysis based on the administrative levels of the city

Variables	(1) High	(2) High	(3) High	(4) Low	(5) Low	(6) Low
lnLQ_MAN	0.100			0.047*		
	(1.66)			(1.94)		
lnLQ_PS8		0.049			0.076	
		(0.70)			(1.03)	
lnCOAG			0.326**			0.154*
			(2.14)			(1.88)
lnPopDensity	− 0.006	− 0.007	− 0.005	− 0.010	− 0.009	− 0.009
	(− 0.96)	(− 1.10)	(− 0.90)	(− 0.89)	(− 0.80)	(− 0.85)
lnTaddSadd	0.092	0.063	0.075	− 0.067***	− 0.078***	− 0.070***
	(1.61)	(1.02)	(1.32)	(− 2.79)	(− 3.74)	(− 3.00)
lnRegulation	0.786***	0.787***	0.800***	0.696***	0.717***	0.708***
	(2.96)	(2.88)	(2.97)	(5.60)	(5.65)	(5.68)
lnSciEdu	− 0.060	− 0.051	− 0.053	− 0.043**	− 0.044**	− 0.042**
	(− 1.55)	(− 1.35)	(− 1.48)	(− 2.16)	(− 2.17)	(− 2.13)
lnuF	− 0.009	− 0.008	− 0.009	− 0.004	− 0.004	− 0.004
	(− 0.88)	(− 0.78)	(− 0.87)	(− 0.90)	(− 0.98)	(− 0.91)
Constant	1.171***	1.200***	0.852**	1.103***	1.113***	0.961***
	(3.17)	(3.23)	(2.08)	(5.55)	(5.57)	(4.54)
Observations	490	490	490	3,444	3,444	3,444
R-squared	0.569	0.566	0.572	0.391	0.391	0.392
Number of cities	35	35	35	246	246	246

Robust t-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

Conclusions and policy recommendations

Exploring the connection between China's IA and green growth is a critical issue under the requirements of the global green and low-carbon development. Based on previous studies, this paper computes GTFP at the city level by applying panel data from 281 prefecture-level cities in China from 2004 to 2017. Besides, we further investigated the effects of various forms of IA on GTFP and its two decomposition factors (EC&TC). Finally, this paper draws the following main conclusions: (1) manufacturing agglomeration plays a significant part in improving the GTFP of cities mainly through promoting internal technological progress. If manufacturing agglomeration increases by 1%, technological progress will increase by 0.03%, and the GTFP of cities will increase by 0.042%; (2) in fact, the agglomeration of producer services can improve technical efficiency but also cause the decline of production technology level. Therefore, the agglomeration of producer services cannot effectively play the agglomeration effect and cause the improvement of GTFP; (3) a higher level of agglomeration formed by the collaboration of manufacturing and producer services has a substantial positive correlation with GTFP. Every 1% rise in the degree of COAG can lead to 0.151% growth in GTFP. However, COAG cannot significantly stimulate the improvement of efficiency and technological progress at present; and (4) for cities whose administrative level is at the provincial capital level or above, or within the urban agglomeration planned by the government, COAG can play a more significant green growth effect. However, for ordinary cities, manufacturing agglomeration is more advantageous to improving GTFP.

Whether it is relatively advanced emerging economies such as India, Brazil, Turkey or other less developed regions, most developing countries are facing the dual pressure of economic development and environmental pollution [40, 76, 82, 90, 91]. Therefore, this paper is not only an effective suggestion for China's case, but also a reference for developing countries according to their own economic structure and development stage. Based on the above findings, this paper holds that insisting on agglomeration development is the only way to achieve scale efficiency and improve the green and sustainable development capacity of cities. It can be said that the COAG

Table 8 Heterogeneity analysis based on inner and outer cities of urban agglomeration

Variables	(1) Inner city	(2) Inner city	(3) Inner city	(4) Outer city	(5) Outer city	(6) Outer city
lnLQ_MAN	0.027			0.074		
	(1.25)			(1.63)		
lnLQ_PS8		0.052			0.111	
		(1.56)			(0.73)	
lnCOAG			0.115**			0.227
			(2.48)			(1.25)
lnPopDensity	− 0.012	− 0.012	− 0.012	− 0.005	− 0.004	− 0.004
	(− 1.01)	(− 0.99)	(− 0.99)	(− 0.51)	(− 0.37)	(− 0.43)
lnTaddSadd	− 0.044**	− 0.047**	− 0.043**	− 0.076*	− 0.100***	− 0.086**
	(− 2.03)	(− 2.17)	(− 2.00)	(− 1.92)	(− 3.24)	(− 2.40)
lnRegulation	0.595***	0.592***	0.600***	0.940***	0.951***	0.953***
	(4.57)	(4.53)	(4.59)	(4.59)	(4.54)	(4.61)
lnSciEdu	− 0.024	− 0.027	− 0.024	− 0.056**	− 0.059**	− 0.055**
	(− 1.05)	(− 1.20)	(− 1.04)	(− 2.16)	(− 2.19)	(− 2.12)
lnuF	− 0.011	− 0.010	− 0.011*	0.003	0.001	0.003
	(− 1.62)	(− 1.58)	(− 1.70)	(0.64)	(0.17)	(0.58)
Constant	1.066***	1.050***	0.954***	1.340***	1.322***	1.124***
	(4.95)	(4.93)	(4.47)	(4.38)	(4.24)	(3.23)
Observations	2170	2170	2170	1764	1764	1764
R-squared	0.448	0.448	0.449	0.360	0.359	0.360
Number of cities	155	155	155	126	126	126

Robust t-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

of manufacturing and producer services is the high-level development goal of the industry. And, it is the key to guiding the rational distribution of manufacturing and producer services in most regions according to the local development status and resource conditions. At the same time, it is necessary to avoid the lazy government behavior of applying the same industrial development plan to different cities.

For the cities with policy and institutional advantages and preferential economic development, it is an effective method to support the growth of urban GTFP based on the deep integration and coordinated development of advanced manufacturing and producer services. On one hand, the governments of these cities should strive to foster the progress of manufacturing to the middle and high end of the global industrial chain, and focus on the expansion of supporting producer services. Meanwhile, guiding firms to give full play to the advantages of resource allocation, deepening the business association and technology penetration of the two industries, is conducive to improving the core competitiveness and economic effect of firms. On the other hand, the government should also encourage and guide the cooperation between universities, research institutes, and firms. It not only improves the capacity of scientific and technological innovation, but also speeds up the transformation of innovation results, thus achieving higher efficiency and lower energy consumption. Technological progress and efficiency improvement will lead to green total factor productivity growth.

For ordinary cities, insisting on the healthy development of the manufacturing industry is the key to green development transformation. The government should give priority to the development of a number of industries with local characteristics. Under the consideration of the capacity of resources and the environment, some backward industries and those industries with overcapacity should be eliminated and curbed. Meanwhile, the government should guide manufacturing firms to accelerate the elimination of backward processes and technologies, while encouraging innovation and following up innovation transformation, so that scientific and technological innovation can bring greater economic benefits. Furthermore, we should learn from China's case, avoiding blindly push forward the strategy of "shifting from a labor-intensive industry to service economy". This strategy greatly

Table 9 Heterogeneity analysis based on different stages of development

Variables	(1) 2004–2011	(2) 2004–2011	(3) 2004–2011	(4) 2012–2017	(5) 2012–2017	(6) 2012–2017
lnLQ_MAN	0.149			0.017		
	(1.56)			(0.56)		
lnLQ_PS8		0.205			0.082	
		(0.85)			(1.47)	
lnCOAG			0.293			0.150*
			(1.25)			(1.71)
lnPopDensity	− 0.009	− 0.005	− 0.007	0.004	0.004	0.003
	(− 0.80)	(− 0.55)	(− 0.70)	(0.31)	(0.31)	(0.27)
lnTaddSadd	− 0.062	− 0.061	− 0.060	− 0.107***	− 0.115***	− 0.110***
	(− 1.01)	(− 1.07)	(− 0.98)	(− 2.98)	(− 3.17)	(− 3.08)
lnRegulation	0.576**	0.549**	0.557**	0.845***	0.849***	0.849***
	(2.37)	(2.16)	(2.23)	(5.11)	(5.09)	(5.19)
lnSciEdu	− 0.063**	− 0.069**	− 0.063**	− 0.054*	− 0.055**	− 0.054*
	(− 2.37)	(− 2.37)	(− 2.33)	(− 1.94)	(− 1.97)	(− 1.90)
lnuF	− 0.005	− 0.009	− 0.007	− 0.004	− 0.003	− 0.003
	(− 0.80)	(− 1.62)	(− 1.21)	(− 0.40)	(− 0.35)	(− 0.35)
Constant	0.908**	0.816**	0.560	1.386***	1.386***	1.252***
	(2.44)	(2.06)	(1.13)	(5.37)	(5.36)	(4.66)
Observations	1,967	1,967	1,967	1,686	1,686	1,686
R-squared	0.271	0.270	0.270	0.461	0.462	0.462
Number of cities	281	281	281	281	281	281

Robust t-statistics in parentheses

***$p < 0.01$

**$p < 0.05$

*$p < 0.1$

affects the efficiency of factor allocation and causes the similarity of the current layout of producer services in different regions and vicious competition between regions. Therefore, the government should relax regulations, return to market dominance and encourage producer services to develop in the direction of the leading manufacturing industry based on their own technologies and formats.

There are still many deficiencies in this paper. Firstly, this paper mainly analyzes the impact of industrial agglomeration on GTFP from a relatively macro perspective, without analyzing the micro mechanism. In the future, we can use micro data of the enterprise to refine research. Meanwhile, although the construction of dynamic panel combined with GMM can moderately solve the endogeneity problem, more literatures tend to construct strictly exogenous instrumental variables. Unfortunately, this paper failed to find appropriate instrumental variables. Hence, more attempts can be made in the future.

Abbreviations
IA: Industrial agglomeration; COAG: Collaborative agglomeration; GTFP: Green total factor productivity.

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Author contributions
ZH: methodology, analyzed data, writing—reviewing and editing. ZC: conceptualization, writing—original draft preparation. XF: supervision. All authors read and approved the final manuscript.

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Availability of data and materials
The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Declarations

Ethics approval and consent to participate
Not applicable.

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The authors declare that they have no competing interests.

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