Can the Yangtze River Delta Urban Agglomeration Policy Promote Green High-quality Development? Evidence from the Digital Economy and Green Total Factor Productivity

Authors: Cai, Jin, Baohang, Hui, and Tan, Li

Source: Journal of Resources and Ecology, 15(1) : 105-116

Published By: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences

URL: https://doi.org/10.5814/j.issn.1674-764x.2024.01.009

J. Resour. Ecol. 2024 15(1): 105-116
DOI: 10.5814/j.issn.1674-764x.2024.01.009
www.jorae.cn

Can the Yangtze River Delta Urban Agglomeration Policy Promote Green High-quality Development? Evidence from the Digital Economy and Green Total Factor Productivity

JIN Cai, HUI Baohang, LI Tan*

College of Economics and Management, Anhui Agricultural University, Hefei 230036, China

Abstract: Urban agglomerations should meet the dual requirements of economic growth and green development, and there is currently an urgent need to improve the efficiency of green development. Therefore, we analyzed the impact of the Yangtze River Delta Urban Agglomeration (YRDUA) policy on the digital economy (DE) and green total factor productivity (GTFP) using the time-varying difference in difference model (DID). The marginal contribution of this study is an evaluation of the long-term effect of the YRDUA policy on green high-quality development. Based on the perspective of the "Porter Hypothesis", this study examined the similarities and differences in the impacts of urban agglomeration on DE and GTFP. The results show that the policy promotes the urban DE index, but significantly inhibits urban GTFP. This means that the overall impact of urban agglomeration policy on green high-quality development in the Yangtze River Delta (YRD) is still in the "weak Porter Hypothesis" state, the technological innovation and efficiency improvement stimulated by urban agglomeration policies are not enough to significantly improve GTFP, and the "strong Porter Hypothesis" is not tenable. In addition, the heterogeneity analysis shows that the policy has a more obvious role in promoting the green high-quality development of central cities, large and medium-sized cities and innovative cities. The level of urban public service supply shows a threshold effect. When it develops to a certain scale, the urban agglomeration policy has significant positive impacts on both DE and GTFP.

Key words: Yangtze River Delta Urban Agglomeration; digital economy; GTFP; time-varying DID; green high-quality development

1 Introduction

In recent years, urbanization strategies have been gradually incorporated into the development policies of many countries (Yang et al., 2015; Fang and Yu, 2017). Globalization and rapid urbanization have given rise to an increasing number of world cities as well as urban agglomerations (Chen et al., 2013), which is conducive to breaking the restrictions of administrative divisions, promoting the free flow of regional factors of production and establishing sound cooperative relations, and ultimately achieving regional economic development (Fang, 2015; Peng et al., 2020; Yu, 2021).

However, sustainable urbanization is one of the serious challenges facing developing countries and regions. The crude model of urban agglomerations with high input, energy consumption and pollution has hindered high-quality economic development (Song et al., 2018; Huang and Liao, 2021). This is contrary to the idea of ensuring a greener urban future. Therefore, determining how to balance the multiple

Received: 2023-05-21 **Accepted:** 2023-08-20
Foundation: The National Natural Science Foundation of China (71873003); The Key Program of the Department of Education of Anhui Province (SK2020A0131); The Research Project on Humanities and Social Sciences for Higher Education of Anhui Province (YJS20210256).
First author: JIN Cai, E-mail: jinc612@outlook.com
***Corresponding author:** LI Tan, E-mail: litan@ahau.edu.cn

Citation: JIN Cai, HUI Baohang, LI Tan. 2024. Can the Yangtze River Delta Urban Agglomeration Policy Promote Green High-quality Development? Evidence from the Digital Economy and Green Total Factor Productivity. *Journal of Resources and Ecology*, 15(1): 105–116.

objectives of sustainable economic development, sustainable environmental improvement and regional coordinated development has become a global focus (Wang et al., 2022).

To address these challenges, the digital economy (DE) and green total factor productivity (GTFP) have become important tools (Chen et al., 2019). As China's economy and society enter the digital era, the proportion of DE in the total economy has expanded year by year. Digital technology can break through the traditional temporal and spatial boundaries, reduce resource misallocation, and realize the intensive integration and efficient use of production factors, thereby improving the efficiency of economic operation and promoting urban green development (Cheng and Jin, 2022; Zhou and Gong, 2022). In addition, GTFP is a revision of traditional total factor productivity that incorporates energy and environmental factors into the economic growth analysis framework, and it is the basis for judging whether a country or region can achieve long-term sustainable development (Ahmed, 2012; Wang et al., 2015). Therefore, increasing the DE and GTFP across the board is the key to achieving green economic transformation and sustainable development.

Urban agglomeration is a typical form in the evolution of urban spatial organization worldwide, and it is the main form of China's new urbanization. Before the reform and opening up, the cities were scattered and developed due to the city-biased policy, and urban development lacked the scale effect of agglomeration (Ma et al., 2018). Since the reform and opening up, China's urban system has been continuously improved, and urban dense areas composed of several urban areas have emerged. By the end of 2019, the urbanization rate of China's permanent population reached 60.6%, and economic activities were increasingly characterized by concentrated development in space and geography, gradually forming a regional development pattern with urban agglomerations as the main body (Guan et al., 2018). Among them, the Yangtze River Delta urban agglomeration (YRDUA) is a region with one of the strongest innovation abilities, the most dynamic economy and the largest absorption of foreign populations in China, further improving the spatial layout of the Reform and Opening-up (Yu et al., 2020). Subsequently, the Chinese government promulgated a number of economic regional plans, proposing that the YRDUA should drive economic transformation and upgrading through innovation, and be built into a world-class city cluster with global influence (Chen et al., 2019). Meanwhile, economic growth relying mainly on investment and factor drivers has brought about serious resource and environmental problems (Sheng et al., 2019), and the role of an urban agglomeration-based development approach to high-quality green economic development cannot be ignored. However, in the period of high-quality development, whether the YRDUA policy can promote green development is a major question.

The urban agglomeration policy integrates otherwise independent cities into a larger city cluster economy (Baas and Brücker, 2010). Within this economy, factors of production flow freely and administrative barriers are relatively low, facilitating the linked development of individual cities (Porter, 2000). Some scholars have studied the economic effects of the city cluster policy and found that the policy has significantly facilitated the movement of technology, capital and population factors (Han et al., 2018; Wang et al., 2019). Simultaneously, the policy helps to promote synergistic economic development within the region (Feng and Wang, 2022). As environmental pollution has become increasingly important, many scholars began to study the effectiveness of urban agglomerations for green development. However, no consensus has been reached regarding the relevant conclusions (Liang et al., 2019). At present, there are three main views: "promotion theory", "inhibition theory" and "uncertainty". The "promotion theory" believes that urban agglomerations can promote economic agglomeration and optimize resource allocation, so their effectiveness for green development is positive (Liu and Li, 2021; Zhao et al., 2022). However, when urban populations become too large, the crowding effect may dominate, with negative effects on economic development and environmental protection (Li and Liao, 2020). Scholars who hold the "uncertainty" view argue that urban agglomerations do not have a simple linear relationship with green development, and some argue that they have a U-shaped relationship (Zhang and Vigne, 2021).

Despite a considerable number of studies, the effectiveness and mechanisms of urban agglomeration policy for green high-quality development remain unclear. The connotation of green high-quality development not only requires the efficiency of economic development, but also green characteristics, that is, the optimal allocation of resources in the production process to achieve the optimal environmentally-friendly output. DE is mainly realized through digitalization and information technology to achieve the optimal allocation of resources, and GTFP takes environmental factors into account. They both play an important role in green high-quality development (Zhou and Gong, 2022). Unfortunately, few studies have comprehensively assessed the effectiveness of urban agglomeration policy for green development. We therefore empirically studied the effectiveness of the policy for DE and GTFP in the YRDUA using 2007–2019 city panel data by following four main steps. First, based on the urban agglomeration policies implemented in batches in 2010, 2014 and 2016, we set up the virtual variables of urban agglomeration policy, and used the time-varying difference in difference (DID) model to evaluate the effectiveness of the policy for green high-quality development. The second step was calculating the green high-quality development level more comprehensively from the perspectives of DE and GTFP. The third was analyzing the heterogeneity based on the central-peripheral cities, urban population size and innovative cities. The fourth was using the threshold regression to discuss the effectiveness of urban public service supply level for its heterogeneity.

2 Theoretical analysis

2.1 The impact of the YRDUA policy on DE

The utility of the DE is a key concern for academics (Zhu and Chen, 2022). At the micro level, digital technology promotes factor cost reduction and resource allocation efficiency. The role of the DE in the macro economy is to promote urban cooperation and innovation, and to increase the frequency of economic innovation; and to generate a "technological spillover" effect, to promote the diffusion of technological innovation, to promote digital industrialization, and to optimize the industrial structure. City clusters are conducive to breaking down administrative boundaries, bringing into play the advantages of resource allocation between regions and effectively promoting innovation in green production technologies (Wang et al., 2022). On the one hand, urban clusters promote factor cost reduction and resource allocation efficiency improvement, creating a "centripetal force" for factor flow. As the central city has advantages in infrastructure optimization and human resources, it can provide greater technical support and infrastructure guarantee for the development of DE (Copeland and Taylor, 2004). On the other hand, urban clusters are conducive to promoting the process of integrated development between cities, in which the market boundaries between different cities have gradually weakened, the barriers to market entry and the reduction of transaction costs have effectively promoted the learning, sharing and overflow of professional knowledge, and expanded the development space of the DE (Luo et al., 2022).

Thus, the following hypothesis is proposed:

H1: The YRDUA policy has significantly improved the DE index levels of cities.

2.2 The effect of the YRDUA policy on GTFP

The measurement of GTFP not only considers the role of traditional input factors and technological innovation factors on economic growth, but also takes energy consumption and environmental factors as important indicators for assessing the green high-quality development (Chen et al., 2022a).

Based on the Porter Hypothesis, according to the degree of innovation, it is further divided into the "weak Porter Hypothesis" and the "strong Porter Hypothesis" (Jaffe and Palmer, 1997). The reason for testing the distinction between the weak and strong hypotheses is that we believe the effectiveness of urban agglomerations is different for DE and GTFP. The former means that environmental regulation can force companies to innovate, thereby reducing the cost of environmental remediation (Hamamoto, 2006); while the latter means that environmental regulation can not only promote enterprise innovation, but also make up for costs through innovation, and ultimately bring about an improvement in the enterprise competitiveness or enterprise performance (Ambec et al., 2013). Using this idea as a reference, green high-quality development also has a "Porter Effect". Therefore, the effectiveness of the YRDUA policy for green high-quality development can be divided into the "weak Porter Hypothesis" (the effectiveness for DE) and the "strong Porter Hypothesis" (the effectiveness for GTFP).

The urban agglomeration policy integrates separate economies into larger ones, helping to break down spatial constraints on economic activity, fully share data resources and significantly reduce transaction costs. However, when the urban population and enterprises are large, the agglomeration uneconomic effect will dominate, resulting in a crowding effect. This will compress the growth space of enterprises, especially high-polluting enterprises, and limit the green technology investment and innovation activities of enterprises. The YRDUA policy cannot improve productivity in the short term, especially GTFP. Therefore, we present hypothesis 2:

H2: The effectiveness of the YRDUA policy for green high-quality development is still at the stage of the "weak Porter hypothesis", and has not significantly improved GTFP.

2.3 Regional heterogeneity of the YRDUA policy

Based on the theory of new economic geography, the agglomeration and diffusion brought about by factor migration caused by the development of urban agglomerations will lead to spatial differentiation in the scale of the regional economy and the level of innovation, and ultimately the formation of a "center-periphery" spatial structure (Stein et al., 2021). Urban agglomerations promote the flow and optimal allocation of traditional production factors such as labor, capital and talents within the region, and they also accelerate the dissemination of innovative factors such as technology and knowledge among regions (Wang et al., 2020). The factors of production and innovation in the traditional sense will follow economic laws, making the above factors concentrate in a certain area and realize the scale effect (Cheng and Jin, 2022). Through the networked and connected development of basic transport facilities, the development of urban agglomerations continues to weaken city boundaries, accelerate the further concentration of economic activities, break the spatial scope of knowledge spillover and talent flow, and enhance social productivity (Wang et al., 2021a). These characteristics will significantly increase the efficiency of knowledge and technology spillovers, thereby facilitating the radiation of digital technologies from central to peripheral cities and enhancing inter-city diffusion effects. However, due to the relative weaknesses of peripheral cities in terms of infrastructure development, policies and regulation, this may lead to the absorption of advantageous resources from the central cities to the peripheral cities, subjecting them to a relatively scarce resource environment and creating a siphoning effect, further distorting the allocation of factors between cities and widening the regional development gap (Duranton and Puga, 2005). Therefore, we present hypothesis 3:

H3: The effectiveness of the YRDUA policy for green high-quality development has regional heterogeneity in the “center periphery” structure.

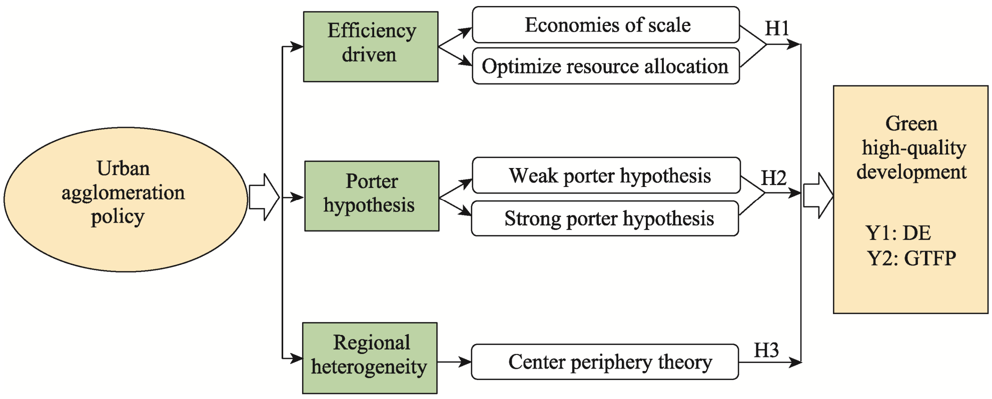

Fig. 1 Impact mechanisms of urban agglomeration policy on DE and GTFP

3 Research design

3.1 Research methods

Since the cities differ in their timing of policy implementation, a time-varying difference (DID) model was used in this study. The effectiveness of the YRDUA policy for green high-quality development can be further divided into the “weak Porter Hypothesis” (the impact on DE) and the “strong Porter Hypothesis” (the impact on GTFP).

$$DE_{it} = \alpha_0 + \alpha_1 DID_{it} + \alpha\, Control_{it} + \gamma_t + \mu_i + \varepsilon_{it} \quad (1)$$

$$GTFP_{it} = \beta_0 + \beta_1 DID_{it} + \beta\, Control_{it} + \gamma_t + \mu_i + \varepsilon_{it} \quad (2)$$

where the subscripts i and t correspond to city and year, respectively. DE_{it} and $GTFP_{it}$ are the explanatory variables, indicating the DE and $GTFP$ of i-city in t-year, respectively. DID_{it} is an interactive item, when i-city implements a policy in t-year, DID_{it} is 1 in the years after t-year, otherwise it is 0. α_1 and β_1 represent the net effects of the policy impacts on DE and GTFP, respectively. $Control_{it}$ are control variables, including *pgdp*, *inter*, *fin*, *fdi* and *ind*. α_0 and β_0 are constant terms. The term γ_t represents the year fixed effect, μ_i represents the urban fixed effect, and ε_{it} denotes the random error term.

3.2 Measurements of variables and descriptions

3.2.1 Dependent variable

Accurate measurement of the DE index at the city level is conducive to obtaining an objective and comprehensive grasp of the level of development of the DE. Some studies have built a digital economy index system based on the development of informatization, i.e., Internet digital transactions. Based on this research, we measured the digital economy using broadband penetration, the number of computer and software employees, total telecommunication services per capita, and mobile phone penetration in light of the availability of relevant data. We used principal component analysis to normalize the above four indicators in order to obtain the DE index.

GTFP contains both expected and non-desired indicators. In terms of the indicators for each input, labor input in this study was measured in terms of the number of employees per unit. Referring to the existing research, this study measured capital investment by using the capital stock of fixed assets estimated by the perpetual inventory method (Zhang, 2008). The indicators of expected and unexpected outputs are shown in Table 1.

Table 1 Input and output indicators and descriptions

First indices	Second indices	Description
Input	Labor	Employees of the unit (10^4 persons)
	Capital	Capital stock of fixed assets (10^4 yuan)
	Energy	Electricity consumption in the society (10^4 kWh)
Expected output	Economic output	Regional GDP (10^4 yuan)
Unexpected output	Environmental contamination	Industrial wastewater (10^4 t)
		Industrial SO_2 (t)
		Industrial soot (t)

With the increasing prominence of environmental constraints, researchers have begun to incorporate environmental constraints into the system of indicators for measuring TFP (Chen et al., 2022b). To this end, in addition to capital and labor inputs, energy consumption has been increased to reflect the constraints of environmental resources on economic growth. There are many methods for measuring GTFP, such as Data Envelopment Analysis (DEA), Solow Growth Accounting (SGA), Stochastic Frontier Analysis (SFA), and the production function method (Wang et al., 2021b). Based on existing research, we calculated GTFP using the SBM-GML model.

Suppose the k-th decision unit (j = 1, 2, ···, n), then there are input vector $x \in R^M$, expected output vector $y^g \in R^{s_1}$, and undesired output vector $y^b \in R^{s_2}$. Additionally, the matrix is $X=\left[x_1,x_2,\cdots,x_n\right]\in R^m\times n$, $Y^g=\left[y_1^g,y_2^g,\cdots,y_n^g\right]$ $\in R^{s_1}\times n$, $Y^b=\left[y_1^b,y_2^b,\cdots,y_n^b\right]\in R^{s_2}\times n$. For decision unit k, as in equation (3):

$$\min\rho=\frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1-\frac{1}{s_1+s_2}\times\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}^g}+\sum_{t=1}^{s_2}\frac{s_t^b}{y_{tk}^b}\right)}$$

$$\text{s.t.}\begin{cases}\sum_{j=1,j\neq k}^{n}\left(x_{ij}\lambda_j-s_i^-\right)\leqslant x_{ik}\\ \sum_{j=1,j\neq k}^{n}\left(y_{rj}\lambda_j+s_r^g\right)\geqslant y_{rk}^g\\ \sum_{j=1,j\neq k}^{n}\left(y_{tj}\lambda_j-s_i^b\right)\leqslant y_{tk}^b\\ \lambda\geqslant 0;s^g\geqslant 0;s^b\geqslant 0;s^-\geqslant 0\end{cases}\tag{3}$$

where λ is the weight vector. The terms s_i^- , s_r^g , and s_i^b are relaxation variables. x_{ij} , y_{rj} , and y_{tj} denote the i-th input, the r-th desired output, and the t-th non-desired output for area j. $\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}$ represents the average degree of inefficiency of the input, and $\frac{\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}^g}+\sum_{t=1}^{s_2}\frac{s_t^b}{y_{tk}^b}}{s_1+s_2}$ represents the average degree of inefficiency of the output. ρ is the efficiency value of the decision unit and it can be greater than 1, so the effective decision unit can be distinguished. The GML index is:

$$GML^{t,t+1}\left(x^{t+1},y^{t+1},b^{t+1};x^t,y^t,b^t\right)=\frac{1+D_G^T\left(x^t,y^t,b^t\right)}{1+D_G^T\left(x^{t+1},y^{t+1},b^{t+1}\right)}\tag{4}$$

If $GML^{t,t+1}$, then the GTFP is less than in the previous period; otherwise, the GTFP increases. Given that the GML productivity index reflects the growth rate of GTFP, the measured index needs to be adjusted accordingly.

3.2.2 Independent variable

The DID term is the independent variable, and this study used the year in which the policy was enacted (2010, 2014 and 2016). When a city is classified as a YRDUA, the *DID* item in the current year and subsequent years is 1; conversely, it is 0. The sample contains a total of 99 cities, with the experimental group comprising the 26 cities included in the YRDUA and the control group comprising its 73 adjacent cities. According to the relevant development plan of the YRDUA (https://www.ndrc.gov.cn/), the policy implementation time points are 2010, 2014 and 2016.

3.2.3 Control variables

In empirically testing the effectiveness of the YRDUA policy for DE and GTFP, five control variables were selected in this study. 1) Per regional GDP (*pgdp*): Economically developed cities have high living standards (Xie et al., 2021), complete infrastructure, and sufficient and stable scientific research investment. Therefore, we used the logarithm of *pgdp* to calculate the regional economic level. 2) Informatization level (*inter*): This study measured the level of urban informatization by the logarithm of the number of Internet broadband households. 3) Financial support (*fin*): This was measured by the loan balance as a percentage of GDP (Li et al., 2020). 4) Foreign direct investment (*fdi*): This study measured FDI by the logarithm of the amount of foreign capital that was actually used. 5) Industrial structure (*ind*): We chose the proportion of the added value of the secondary industry in the regional GDP to express this variable.

After data collection and index calculation, this study further identified the outliers and filled in the missing values using interpolation methods for each variable during processing, and finally obtained relatively complete panel data for research and analysis. The detailed descriptions are provided in Table 2.

Table 2 Variables and descriptive statistics

Variable	Description	Number	Mean	SD	Min	Max
DE	Digital economy	1287	–0.17	0.64	–0.98	8.81
GTFP	Green total factor productivity	1287	1.43	0.36	0.29	5.73
DID	Policy dummy variable	1287	0.16	0.37	0.00	1.00
ln *pgdp*	Logarithm of per regional GDP	1287	10.58	0.65	8.68	12.20
ln *inter*	The logarithmic number of Internet broadband households	1287	13.18	0.96	10.54	17.76
ln *fin*	Loan balance as a percentage of GDP	1287	17.18	1.07	14.52	21.40
ln *fdi*	Logarithm of actually used foreign capital	1287	10.62	1.26	7.07	14.46
Ind	Proportion of the added value of the secondary industry in the regional GDP	1287	0.50	0.09	0.15	0.77

4 Results and discussion

We separately assessed the effectiveness of the YRDUA policy for DE and GTFP. In addition, the above two indicators were assessed using the parallel trend and placebo tests.

4.1 The spatiotemporal distribution of DE and GTFP in YRDUA

In order to analyze the changes in the DE and GTFP of the YRDUA before and after the implementation of the policy, we produced a spatiotemporal distribution map (Fig. 2). The cities on the red boundary in Fig. 2 are the YRDUA, namely the experimental group cities, and the rest are the control group cities.

The spatiotemporal distribution of DE in the YRDUA is shown in three figures (Fig. 2a–2c). Obviously, the DE of some cities in the experimental group increased slightly from 2007 to 2013, and the DE of most cities in the experimental group increased significantly from 2013 to 2019. This may be because the environmental effect of the policy lags behind. The diffusion effect of DE in the YRDUA was obvious from 2007 to 2019, and the DE in the surrounding cities also increased slightly.

The spatiotemporal distribution of GTFP is shown in Fig. 2d–2f. From 2007 to 2019, the GTFP of most cities in the experimental group gradually decreased, except for Shanghai, Ningbo, Taizhou and other coastal cities where the GTFP did not change significantly. Based on spatial effects, the GTFP of the cities around the YRDUA also decreased slightly from 2007 to 2019.

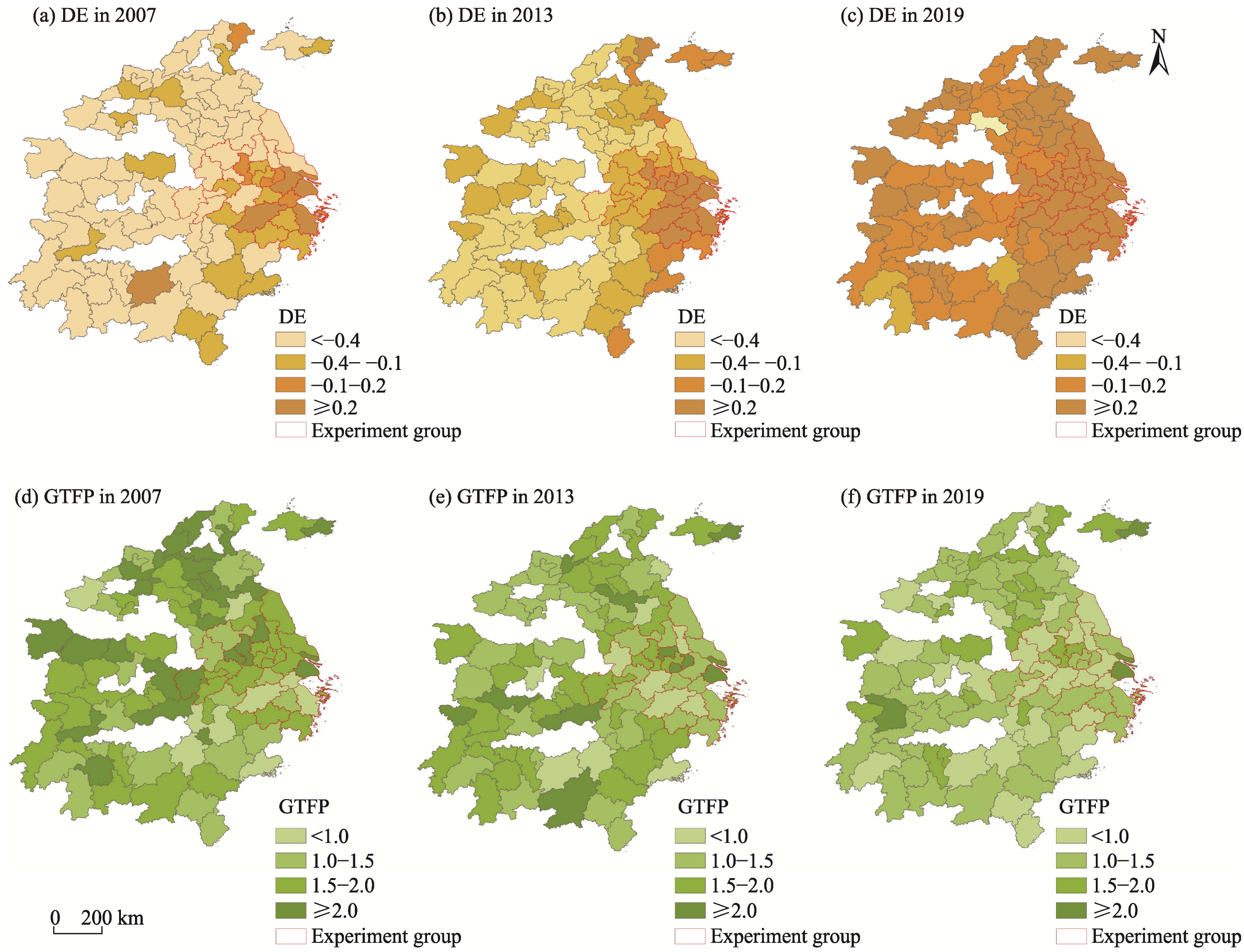

Fig. 2 The spatiotemporal distributions of (a-c) DE and (d-f) GTFP in 2007, 2013 and 2019

4.2 Empirical results

This study found that the effectiveness of the YRDUA policy for DE was positive (Table 3). On the contrary, the effectiveness of the policy for the GTFP was negative. This difference shows that the effectiveness of the YRDUA policy for DE and GTFP was heterogeneous, and the “weak Porter Hypothesis” was established while the “strong Porter Hypothesis” was not. The above results verify Hypotheses 1 and 2. This means that the overall effectiveness of YRDUA policy for green development is still in the “weak Porter Hypothesis”, with the YRDUA policy promoting technological progress and improving the digital economy. However, due to the uncertainty of investments in technology development and environmental costs, it was not sufficient to increase GTFP.

Table 3 The results of the models

Variable	DE		GTFP	
	(1)	(2)	(3)	(4)
DID	0.143** (0.058)	0.200*** (0.048)	–0.108** (0.045)	–0.165*** (0.035)
ln *pgdp*		0.482*** (0.096)		0.192** (0.095)
ln *inter*		0.539** (0.269)		–0.139** (0.065)
ln *fin*		–0.393** (0.168)		0.158 (0.116)
ln *fdi*		–0.045** (0.021)		0.057** (0.025)
Ind		–1.056** (0.335)		–0.682* (0.345)
Constant	–0.539*** (0.023)	–4.453** (1.995)	1.280*** (0.018)	7.170*** (2.195)
Time FE	✓	✓	✓	✓
Individual FE	✓	✓	✓	✓
R^2	0.344	0.619	0.054	0.010
N	1287	1287	1287	1287

Note: * P<0.1, ** P<0.05, *** P<0.01; Robust standard errors are shown in parentheses.

4.3 Robustness tests

4.3.1 Parallel trend test

Until the policy is implemented, there should be no systemic differences in the development trends between cities. Therefore, we used Event Study to extend the above equation and construct a dynamic double difference model, which was set as follows.

$$Y_{it} = \beta_0 + F_k DID_{i,t-k} + L_m DID_{i,t+m} + \lambda Control_{it} + \gamma_t + \mu_i + \varepsilon_{it} \tag{5}$$

where $DID_{i,t-k}$ denotes the antecedent term for period $k(k=1,\cdots, k)$ of policy implementation. $DID_{i,t+m}$ denotes the lag term for the m (m=1, $\cdots$, m) period of policy implementation. Factors F_k and L_m represent the net effect of the policy impact. $Control_{it}$ are control variables, and λ is its coefficient. β_0 is constant term. The term γ_t represents the year fixed effect, μ_i represents the urban fixed effect, and ε_{it} denotes the random error term.

Based on the data in Fig. 3a, the coefficient of DE before the implementation of the YRDUA policy was not significant, which satisfies the prerequisites for using the DID model. In addition, the coefficient of DE was not significant within two years of the policy's implementation. Afterward, the coefficient gradually increased and became significant, indicating that the policy had a lagged effect on DE. From Fig. 3b, before the implementation of the policy, the effect of the YRDUA policy on GTFP was not significant. After the implementation of the policy, its effect on GTFP was negative, indicating that the DID model with GTFP satisfies the parallel trend test.

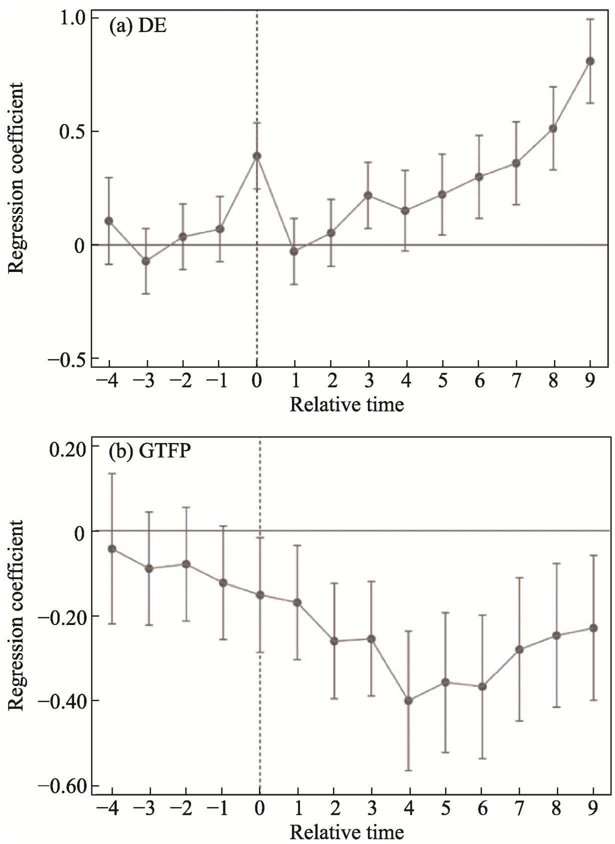

Fig. 3 Parallel trend test results

4.3.2 Placebo test

According to Lu et al. (2017), 26 cities were randomly selected from among the 99 cities as pseudo-treatment groups and control groups, and each group randomly generated the year of policy occurrence to reconstruct the policy interaction items. To prevent the effects of random small probability events on the placebo test, we conducted 500 cycles of the experiment to obtain 500 coefficient estimates and plot their kernel density. The results are shown in Fig. 4. The results of the 500 randomized experiments were all non-significant, demonstrating that the results are robust.

5 Heterogeneity analysis

5.1 Center-periphery cities

Based on the metropolitan pattern of "One Core and Five Circles" in the Outline of the YRD Regional Integration Development Plan, the 26 cities of Hefei, Nanjing, Ningbo, Hangzhou, Suzhou, Wuxi, Changzhou and Shanghai were set as the central cities, while the remaining 18 cities were the peripheral cities. From a "center-periphery" perspective, the YRDUA policy mainly contributed to the growth of DE in the central cities, with no significant impact on GTFP

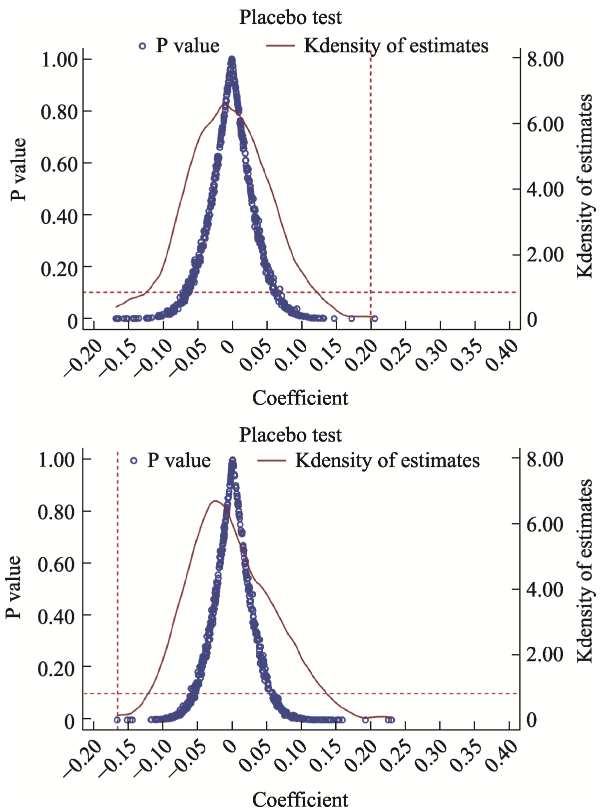

Fig. 4 Placebo test results

(Table 4); while the YRDUA policy had no effect on the DE and GTFP of peripheral cities. These results validate Hypothesis 3.

The policy has promoted the industrial upgrading of the YRDUA, promoted the concentration of labor force, various high-quality resources and capital in the central cities, and produced a "siphon effect" on the neighboring cities; thus the development of the small cities faces great challenges. At the same time, investment in the service sector in urban agglomerations is increasing. Heavy industrial firms may be squeezed out of the central cities, prompting them to move to the surrounding cities, creating a phenomenon of "pollution shelters". This shift will have a negative effect on the industrial upgrading and economic development of the surrounding cities.

Table 4 Heterogeneity of the center-periphery cities

Variable	Central cities		Peripheral cities	
	DE	GTFP	DE	GTFP
DID	0.423* (0.217)	–0.072 (0.179)	0.001 (0.044)	–0.003 (0.065)
Control variables	Yes	Yes	Yes	Yes
Constant	0.341*** (0.081)	9.453*** (6.741)	–4.385* (2.308)	9.980*** (3.276)
Time FE	✓	✓	✓	✓
Individual FE	✓	✓	✓	✓
R^2	0.229	0.013	0.839	0.054

Note: * P<0.1, ** P<0.05, *** P<0.01. Robust standard errors are shown in parentheses.

5.2 City population scales

The impacts of the YRDUA policy on DE and GTFP may differ due to the scale effect and the crowding effect. Therefore, we divided the cities in the YRD according to the population size based on the data of the permanent population of each city to explore the heterogeneity of the YRDUA policy on green high-quality development at the city scale.

The results (Table 5) show that the YRDUA policy had no effect on the DE of small cities. But for large and medium-sized cities, the effectiveness of the policy for DE was positive. These results suggest that the policy produced a stronger boost to the DE in large cities. This is mainly because the large and medium-sized cities have large permanent populations, and under the promotion of an urban agglomeration policy, more scientific and technological innovation talents can be cultivated. Simultaneously, after the implementation of the policy, the economic and technological levels of large and medium-sized cities are at the forefront of the country, so their comparative advantages are more prominent. Finally, large cities are relatively rich in resources, so the foundation and potential for green technology innovation are good, which can effectively promote green development. The effectiveness of the YRDUA policy for the GTFP of cities of all population sizes was negative. However, it is worth noting that the negative effect of the YRDUA policy on the GTFP in cities with populations of 3–6 million was minimal.

Table 5 Heterogeneity of city population scales

Variable	Small cities (≤3 million)		Medium-sized cities (3–6 million)		Large cities (>6 million)	
	DE	GTFP	DE	GTFP	DE	GTFP
DID	0.092 (0.055)	–0.311** (0.089)	0.170*** (0.046)	–0.106* (0.059)	0.378* (0.202)	–0.112** (0.050)
Control variables	✓	✓	✓	✓	✓	✓
Constant	–4.472*** (1.397)	–4.331 (7.566)	–3.140** (1.529)	6.547*** (2.109)	5.241 (6.895)	13.185*** 0.0155
Time FE	✓	✓	✓	✓	✓	✓
Individual FE	✓	✓	✓	✓	✓	✓
R^2	0.792	0.040	0.793	0.017	0.001	0.016

Note: * P < 0.1, ** P < 0.05, *** P < 0.01. Robust standard errors are shown in parentheses. "≤ 3 million", "3–6 million" and "> 6 million" refer to the resident population of less than 3 million, 3 million to 6 million and more than 6 million respectively.

5.3 Innovative cities

Innovative city construction can enhance urban innovation capabilities, thereby promoting sustainability. Therefore, we divided the YRDUA into innovative cities and non-innovative cities according to the Notice on Promoting the National Innovative Cities Pilot Work issued by the National Development and Reform Commission.

The results (Table 6) show that the YRDUA policy had a positive effect on the DE in both types of cities, and the policy had a greater effect on the DE of innovative cities than that of non-innovative cities. The main reason is that the YRDUA policy can produce a stronger technological innovation effect in innovative cities. The implementation of the policy can force cities to innovate production technologies and transform production methods. That is, the policy is more effective in promoting the green development of innovative cities. However, the effectiveness of YRDUA policy for the GTFP in both types of cities has been significantly negative.

Table 6 Heterogeneity of innovative city

Variable	Innovative cities		Non-innovative cities	
	DE	GTFP	DE	GTFP
DID	0.213***	–0.171***	0.118***	–0.132**
	(0.102)	(0.042)	(0.041)	(0.058)
Control variables	✓	✓	✓	✓
Constant	0.227	9.641***	–3.473**	6.279**
	(5.808)	(3.387)	(1.304)	(2.480)
Time FE	✓	✓	✓	✓
Individual FE	✓	✓	✓	✓
R^2	0.192	0.008	0.796	0.011

Note: * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$. Robust standard errors are shown in parentheses.

5.4 City public service supply level

The public service supply level is an essential manifestation of the competitiveness of a city, and it is also an important factor in attracting the inflow of labor and other factors. Therefore, the effect of the YRDUA policy may be affected by different levels of public service supply. In this case, the urban agglomeration policy does not simply have a linear relationship with DE and GTFP. Therefore, we further established a threshold model based on equation 3, and this model can identify the effectiveness of YRDUA policy for DE and GTFP in the different threshold areas. The model was constructed as follows.

$$\begin{aligned} Y_{it} = \beta_0 + \beta_1 DID_{it} \times I\left(X_{it} \leqslant U_1\right) + \\ \beta_2 DID_{it} \times I\left(U_1 < X_{it} \leqslant U_2\right) + \\ \beta_3 DID_{it} \times I\left(X_{it} > U_2\right) + \\ \pi\, Control_{it} + \gamma_t + \mu_i + \varepsilon_{it} \end{aligned} \tag{6}$$

where $I(*)$ is an indicative function. X_{it} is the threshold variable. U_i is the potential threshold variable. Drawing on existing studies (Lu et al., 2019), we used the number of hospitals and health centers to measure the city public service supply level. U_1 and U_2 are different threshold values. β_0 is a constant term, while β_1, β_2 and β_3 represent the net effects of policy impact, respectively. $Control_{it}$ are control variables, and π is its coefficient. The term γ_t represents the year fixed effect, μ_i represents the urban fixed effect, and ε_{it} denotes the random error term.

In the DE model, when the city public service supply level is lower than U_1, the policy has a positive effect on DE; but when the city public service supply level is between the threshold values U_1 and U_2, the YRDUA policy has a positive effect on DE. However, when the city public service supply level is greater than U_2, the coefficient of *DID* is significantly negative. This relationship shows that when the city public service supply level is too large, the promoting effect of the YRDUA policy on DE is constrained.

In the GTFP model, when the city public service supply level is lower than U_1, the effectiveness of the YRDUA policy for GTFP is not significant. When the city public service supply level is between U_1 and U_2, the effectiveness of the policy for GTFP is significantly positive. However, when the city public service supply level is greater than the threshold value U_2, it will strengthen the negative effectiveness of the policy for GTFP.

Table 7 Threshold regression results

Variable	DE	GTFP
DID ($U \leqslant U_1$)	0.066** (0.032)	–0.005 (0.031)
DID	6.175***	0.829***
($U_1 < U \leqslant U_2$)	(0.256)	(0.111)
DID	–1.385***	–0.222**
($U > U_2$)	(0.135)	(0.110)
Constant	–3.114*** (0.363)	1.430*** (0.008)
Time FE	✓	✓
Individual FE	✓	✓
R^2	0.538	0.028

Note: * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$. Robust standard errors are shown in parentheses.

6 Discussion

Urban agglomerations are rising rapidly, and the coordinated development of China's regional economy is entering a new stage. The YRDUA has become one of the most active regions in the world economy. Simultaneously, the lack of urban resources and deterioration of the ecological environment are becoming increasingly serious, and the environmental risks and costs cannot be underestimated (Yang and Cai, 2020). For example, Han et al. (2014) found a positive relationship between urban built-up area, population size and $PM_{2.5}$. Sprawling urbanization is an important factor in exacerbating environmental pollution (Bereitschaft and Debbage, 2013; Jiang et al., 2022). China urgently needs to move from an extensive development model to a sustainable model. The DE is considered to be a new driving force for transforming the economic development mode, promoting resource conservation, and improving ecological efficiency, and it is an important booster for achieving green economic development. Meanwhile, GTFP adds environmental elements to the traditional TFP. They are both indicators for measuring the green high-quality development.

Numerous studies have analyzed the effect of urban agglomerations on productivity (Cheng et al., 2019; Yu, 2021), but few have addressed the green high-quality development. Some studies have indirectly suggested that urban agglomerations are beneficial for productivity gains (He et al., 2019). However, there is no direct test of their impacts on DE and GTFP. In addition, urban agglomerations have multi-center, multi-level and multi-node network characteristics. The effectiveness of urban agglomeration policy for green high-quality development is heterogeneous. Can the YRDUA policy boost the coordinated development of central and surrounding cities? What are the heterogeneous effects of city population scales, innovative cities, and different city public service supply levels? Answering these questions can provide guides for environmentally sustainable development and coordinated regional development around the world. As a result of limited empirical evidence, this study attempted to measure GTFP using the SBM-GML model. We then discussed the mechanism of the YRDUA policy on DE and GTFP from both theoretical and empirical aspects, deepening the research on the effect of urban agglomeration policy.

This study may provide the following contributions. First, we supplement the theoretical research on urban agglomeration policy from a theoretical perspective. We focus on the spatial spillover effects and regional heterogeneity of YRDUA policy. Another promising finding was that the YRDUA policy can enhance the GTFP of adjacent cities and the policy has positive implications for peripheral economies.

This study still had the following shortcomings. First, when calculating unexpected output, we did not take CO_2 into account. In the current carbon neutral context, the inclusion of CO_2 makes sense. However, data limitations prevented us from measuring such a GTFP. Second, in the theoretical analysis section, we assumed a relationship between economic agglomeration and GTFP, and perhaps the congestion effect also has an impact on GTFP. Third, in order to test the hypotheses as accurately as possible, we only selected the YRDUA, which has a relatively large economy, as the subject of our study, but we did not consider other city clusters.

7 Conclusions and policy implications

7.1 Conclusions

According to the data from 99 municipalities in and around YRDUA from 2007 to 2019, we used the DID model to analyze the effectiveness of the policy for DE and GTFP. We found that the effectiveness of the YRDUA policy for green high-quality development has a “Porter Effect”, which can be divided into the “weak Porter Hypothesis” and the “strong Porter Hypothesis”.

The main findings are as follows. 1) The YRDUA policy positively promotes DE and has a negative effect on GTFP. After the robustness and placebo tests, the results remained robust. The effectiveness of the YRDUA policy for DE and GTFP is heterogeneous. The “weak Porter Hypothesis” is valid and the “strong Porter Hypothesis” is not, which means that the overall effectiveness of the YRDUA policy for green high-quality development level is still in the state of the “weak Porter Hypothesis”. Due to the lag of urban agglomeration policy and environmental costs, it is not enough to improve the urban GTFP. 2) Through heterogeneity analysis, the YRDUA policy was found to have an effect on the central cities, large and medium-sized cities and innovative cities. 3) The public service supply level has a threshold effect.

7.2 Policy implications

Urban agglomerations are burdened with the dual requirements of economic growth and green high-quality development, and urgently need to advance the efficiency of green development. First, considering that air and water pollution problems can cross regional administrative boundaries, there is an urgent need to develop a set of tools, incentives and systems for effective ecological and environmental management. We need to take advantage of the construction of urban agglomerations to promote environmental legislation that crosses administrative boundaries and to improve the green high-quality development level by effective environmental enforcement. Second, the urban agglomerations should rely on the innovative effect of central cities. This should actively strengthen the capacities of peripheral cities for secondary development and technological innovation, enhance top-level design, optimize the productivity layout of urban agglomerations by addressing environmental and resource constraints, and promote the green upgrading of industries in urban agglomerations and peripheral cities on all fronts. Third, governments should improve targeted public services for green high-quality development. Simultaneously, full attention should be given to its multifaceted actual needs, in order to increase population welfare, attract population inflow, alleviate the imbalance of population factor flow, and strive to promote the simultaneous improvement of DE and GTFP.

References

Ahmed E M. 2012. Green TFP intensity impact on sustainable East Asian productivity growth. *Economic Analysis & Policy*, 42(1): 67–78.

Ambec S, Cohen M A, Elgie S, et al. 2013. The Porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Review of Environmental Economics and Policy*, 7(1): 2–22.

Baas T, Brücker H. 2010. Macroeconomic impact of eastern enlargement on Germany and UK: Evidence from a CGE model. *Applied Economics Letters*, 17(2): 125–128.

Bereitschaft B, Debbage K. 2013. Urban form, air pollution, and CO_2 emissions in large US metropolitan areas. *The Professional Geographer*, 65(4): 612–635.

Chen G B, Wu J Q, Li Y. 2022a. Digital economy, green technology innovation and high-quality economic development. *Statistics & Decision*, 38(23): 11–16. (in Chinese)

Chen J, Abbas J, Najam H, et al. 2022b. Green technological innovation, green finance, and financial development and their role in green total factor productivity: Empirical insights from China. *Journal of Cleaner Production*, 382: 135131. DOI: 10.1016/j.jclepro.2022.135131.

Chen L, Zhang X, He F, et al. 2019. Regional green development level and its spatial relationship under the constraints of haze in China. *Journal of Cleaner Production*, 210: 376–387.

Chen M, Liu W, Tao X. 2013. Evolution and assessment on China's urbanization 1960–2010: Under-urbanization or over-urbanization? *Habitat International*, 38: 25–33.

Cheng Y, Shao T, Lai H, et al. 2019. Total-factor eco-efficiency and its influencing factors in the Yangtze River delta urban agglomeration, China. *International Journal of Environmental Research and Public Health*, 16(20): 1–14.

Cheng Z, Jin W. 2022. Agglomeration economy and the growth of green total-factor productivity in Chinese industry. *Socio-Economic Planning Sciences*, 83: 101003. DOI: 10.1016/j.seps.2020.101003.

Copeland B R, Taylor M S. 2004. Trade, growth, and the environment. *Journal of Economic Literature*, 42(1): 7–71.

Duranton G, Puga D. 2005. From sectoral to functional urban specialisation. *Journal of Urban Economics*, 57(2): 343-370.

Fang C. 2015. Important progress and future direction of studies on China's urban agglomerations. *Journal of Geographical Sciences*, 25(8): 1003–1024.

Fang C, Yu D. 2017. Urban agglomeration: An evolving concept of an emerging phenomenon. *Landscape and Urban Planning*, 162: 126–136.

Feng R, Wang K. 2022. The direct and lag effects of administrative division adjustment on urban expansion patterns in Chinese mega-urban agglomerations. *Land Use Policy*, 112: 105805. DOI: 10.1016/j.landusepol.2021.105805.

Guan X, Wei H, Lu S, et al. 2018. Assessment on the urbanization strategy in China: Achievements, challenges and reflections. *Habitat International*, 71: 97–109.

Hamamoto M. 2006. Environmental regulation and the productivity of Japanese manufacturing industries. *Resource and Energy Economics*, 28(4): 299–312.

Han F, Xie R, Fang J, et al. 2018. The effects of urban agglomeration economies on carbon emissions: Evidence from Chinese cities. *Journal of Cleaner Production*, 172: 1096–1110.

Han L, Zhou W, Li W, et al. 2014. Impact of urbanization level on urban air quality: A case of fine particles ($PM_{2.5}$) in Chinese cities. *Environmental Pollution*, 194: 163–170.

He Y, Zhou G, Tang C, et al. 2019. The spatial organization pattern of urban-rural integration in urban agglomerations in China: An agglomeration-diffusion analysis of the population and firms. *Habitat International*, 87: 54–65.

Huang Y, Liao R. 2021. Polycentric or monocentric, which kind of spatial structure is better for promoting the green economy? Evidence from Chinese urban agglomerations. *Environmental Science and Pollution Research*, 28(41): 57706–57722.

Jaffe A B, Palmer K. 1997. Environmental regulation and innovation: A panel data study. *Review of Economics and Statistics*, 79(4): 610–619.

Jiang N, Jiang W, Zhang J, et al. 2022. Can national urban agglomeration construction reduce $PM_{2.5}$ pollution? Evidence from a quasi-natural experiment in China. *Urban Climate*, 46: 101302. DOI: 10.1016/j.uclim.2022.101302.

Li K, Qu J, Wei P, et al. 2020. Modelling technological bias and productivity growth: A case study of China's three urban agglomerations. *Technological and Economic Development of Economy*, 26(1): 135–164.

Li T, Liao G. 2020. The heterogeneous impact of financial development on green total factor productivity. *Frontiers in Energy Research*, 8: 29. DOI: 10.3389/fenrg.2020.00029.

Liang L, Wang Z, Li J. 2019. The effect of urbanization on environmental pollution in rapidly developing urban agglomerations. *Journal of Cleaner Production*, 237: 117649. DOI: 10.1016/j.jclepro.2019.117649.

Liu T, Li Y. 2021. Green development of China's Pan-Pearl River Delta mega-urban agglomeration. *Scientific Reports*, 11(1). DOI: 10.1038/s41598-021-95312-z.

Lu J, Li B, Li H. 2019. The influence of land finance and public service supply on peri-urbanization: Evidence from the counties in China. *Habitat International*, 92: 102039. DOI: 10.1016/j.habitatint.2019.102039.

Lu Y, Tao Z, Zhu L. 2017. Identifying FDI spillovers. *Journal of International Economics*, 107: 75–90.

Luo S, Yimamu N, Li Y, et al. 2022. Digitalization and sustainable development: How could digital economy development improve green innovation in China? *Business Strategy and the Environment*, 32(4): 1847–1871.

Ma L, Cheng W, Qi J. 2018. Coordinated evaluation and development model of oasis urbanization from the perspective of new urbanization: A case study in Shandan County of Hexi Corridor, China. *Sustainable Cities and Society*, 39: 78–92.

Peng J, Lin H, Chen Y, et al. 2020. Spatiotemporal evolution of urban agglomerations in China during 2000–2012: A nighttime light approach. *Landscape Ecology*, 35: 421–434.

Porter M E. 2000. Location, competition, and economic development: Local clusters in a global economy. *Economic Development Quarterly*, 14(1): 15–34.

Sheng Y, Zhao J, Zhang X, et al. 2019. Innovation efficiency and spatial spillover in urban agglomerations: A case of the Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta. *Growth and Change*, 50(4): 1280–1310.

Song M, Chen Y, An Q. 2018. Spatial econometric analysis of factors influencing regional energy efficiency in China. *Environmental Science and Pollution Research*, 25: 13745–13759.

Stein J, Buck M, Bjørnå H. 2021. The centre–periphery dimension and trust in politicians: The case of Norway. *Territory, Politics, Governance*, 9(1): 37–55.

Wang B, Liu G T. 2015. Energy conservation and emission reduction and China's green economic growth—Based on a total factor productivity perspective. *China Industrial Economics*, (5): 57–69. (in Chinese)

Wang F, Wei X, Liu J, et al. 2019. Impact of high-speed rail on population mobility and urbanisation: A case study on Yangtze River Delta urban agglomeration, China. *Transportation Research Part A*: *Policy and Practice*, 127: 99–114.

Wang H, Cui H, Zhao Q. 2021a. Effect of green technology innovation on green total factor productivity in China: Evidence from spatial Durbin model analysis. *Journal of Cleaner Production*, 288: 125624. DOI: 10.1016/j.jclepro.2020.125624.

Wang J, Han Q, Du Y. 2022. Coordinated development of the economy, society and environment in urban China: A case study of 285 cities. *Environment*, *Development and Sustainability*, 24(11): 12917–12935.

Wang L, Xue Y, Chang M, et al. 2020. Macroeconomic determinants of high-tech migration in China: The case of Yangtze River Delta urban agglomeration. *Cities*, 107: 102888. DOI: 10.1016/j.cities.2020.102888.

Wang M, Pang S, Hmani I, et al. 2021b. Towards sustainable development: How does technological innovation drive the increase in green total factor productivity? *Sustainable Development*, 29(1): 217–227.

Xie R, Fu W, Yao S, et al. 2021. Effects of financial agglomeration on green total factor productivity in Chinese cities: Insights from an empirical spatial Durbin model. *Energy Economics*, 101: 105449. DOI: 10.1016/j.eneco.2021.105449.

Yang Y, Cai Z. 2020. Ecological security assessment of the Guanzhong Plain urban agglomeration based on an adapted ecological footprint model. *Journal of Cleaner Production*, 260: 120973. DOI: 10.1016/j.jclepro.2020.120973.

Yang Z, Hao P, Cai J. 2015. Economic clusters: A bridge between economic and spatial policies in the case of Beijing. *Cities*, 42: 171–185.

Yu B. 2021. Urban spatial structure and total-factor energy efficiency in Chinese provinces. *Ecological Indicators*, 126: 107662. DOI: 10.1016/j.ecolind.2021.107662.

Yu X, Wu Z, Zheng H, et al. 2020. How urban agglomeration improve the emission efficiency? A spatial econometric analysis of the Yangtze River Delta urban agglomeration in China. *Journal of Environmental Management*, 260: 110061. DOI: 10.1016/j.jenvman.2019.110061.

Zhang D, Vigne S A. 2021. How does innovation efficiency contribute to green productivity? A financial constraint perspective. *Journal of Cleaner Production*, 280: 124000. DOI: 10.1016/j.jclepro.2020.124000.

Zhang J. 2008. Estimation of China's provincial capital stock (1952–2004) with applications. *Journal of Chinese Economic and Business Studies*, 6(2): 177–196.

Zhao X, Nakonieczny J, Jabeen F, et al. 2022. Does green innovation induce green total factor productivity? Novel findings from Chinese city level data. *Technological Forecasting and Social Change*, 185: 122021. DOI: 10.1016/j.techfore.2022.122021.

Zhou L, Gong Z M. 2022. The impact of digital economy level on green high-quality development in Chinese cities. *Economic Geography*, 42(11): 133–141. (in Chinese)

Zhu W, Chen J. 2022. The spatial analysis of digital economy and urban development: A case study in Hangzhou, China. *Cities*, 123: 103563. DOI: 10.1016/j.cities.2022.103563.

长三角城市群政策能否促进绿色高质量发展？基于数字经济和绿色全要素生产率的证据

靳　财，惠宝航，李　坦

安徽农业大学经济管理学院，合肥 230036

摘　要：城市群应满足经济增长和绿色发展的双重要求，提高绿色发展效率迫在眉睫。因此，我们利用渐进双重差分模型（DID）分析了长三角城市群政策对数字经济和绿色全要素生产率的影响。本研究的贡献是：评估了长三角城市群政策对绿色高质量发展的长期影响；并基于“波特假说”视角，考察了城市群政策对数字经济和绿色全要素生产率影响的异同。结果显示，长三角城市群政策提高了城市数字经济水平，但明显抑制了绿色全要素生产率。这说明该政策对长三角地区绿色高质量发展的整体影响仍处于“弱波特假说”状态，城市群政策激发的技术创新和效率提升不足以显著提高绿色全要素生产率，“强波特假说”不成立。异质性分析表明，该政策对中心城市、大中城市和创新型城市的绿色高质量发展的促进作用更为明显。城市公共服务供给水平具有门槛效应，当其发展到一定规模时，长三角城市群政策对数字经济和绿色全要素生产率有明显的积极影响。

关键词：长三角城市群；数字经济；绿色全要素生产率；渐进 DID；绿色高质量发展