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Impacts of Urban Development on Regional Green Development Efficiency—A Case of the Yangtze River Delta in China

Dian Li [1], Ziheng Shangguan [2,*], Malan Huang [2], Xinyue Zhang [1] and Lu Tang [1]

[1] School of Business, Hohai University, Nanjing 211100, China; eesanmao@hhu.edu.cn (D.L.); chzxy7@hotmail.com (X.Z.); tanglu1806@163.com (L.T.)
[2] School of Business, Hubei University, Wuhan 430061, China; huangml2019@hubu.edu.cn
* Correspondence: sgzh@hubu.edu.cn

Abstract: Green development is a significant concept that cannot be ignored in contemporary society. However, in the context of China's transition from high-speed growth to high-quality development, the complex impact of urban development has brought great challenges to the urban green environment. In this paper, the impact of urban development on green development efficiency (GDE) was studied. First and foremost, a Super-SBM model was introduced to measure the GDE of 41 cities in the Yangtze River Delta during 2009–2018. Moreover, a Tobit model was used to analyze the correlation between four urban development factors, including economic development and GDE. According to the results, the mean GDE of the Yangtze River Delta is 0.824, and the GDE in most cities there has shown a fluctuating growth trend in this decade. By comparison, the GDEs of coastal cities and cities in the southeast of the Yangtze River Delta were generally higher than those of cities in the north, indicating that the green development is geographically unbalanced, and there is spatial heterogeneity in the area studied. The study's results also suggest that the urban economic development, innovation level, and government planning play a significant role in stimulating urban green development, and that the expansion of urban construction area hinders the improvement of GDE.

Keywords: urban development; green development efficiency; Super-SBM model; Tobit model

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1. Introduction

In the past few decades, large numbers of people have moved from rural areas to cities. According to statistics, 55% of the world's population now lives in urban areas, and the World Bank predicts that this number will increase by 1.5 times to 6 billion by 2045 [1]. Urban development has long been linked to human development and progress. Urban development can contribute to sustainable growth by boosting productivity and enhancing innovation, since more than 80% of global GDP comes from cities [2]. During the rapid expansion of cities, natural habitats and hydrological systems are disrupted, and the energy flow and nutrient cycling are changed, causing the most immediate impact on the environment [3]. In addition, COVID-19 is still ravaging the world, with profound implications for the international political and economic landscape. Although the upward trend of global carbon emissions has been temporarily reversed due to economic downturn and epidemic prevention and control, the long-term solution to climate change remains to practice the concept of green development, promote low-carbon transformation of society, and strengthen international cooperation on climate change [4]. Therefore, it has become an international consensus to minimize the external damage to the environment caused by extensive human activities in the urban development process, so as to promote green recovery of the world economy [5].

Environmental problems caused by economic development—such as climate warming, vegetation destruction, and air pollution—are most troubling and complex global issues. Particularly, the process of achieving modernization of infrastructure in some countries has caused great harm to the "economy–society–resource–environment" system [6]. In this context, it has been an inevitable choice to advocate green development during economic transition. Fawzy et al. (2020) reviewed the main strategies for climate change mitigation, including conventional measures, negative emissions, and radiative forcing geoengineering, arguing that conventional mitigation efforts alone are not sufficient to meet the targets set out in the Paris Agreement [7]. Osman et al. (2021) discussed the latest advances in carbon capture, storage, and utilization technologies to contribute to climate change mitigation [8], reporting that the integration between bioenergy and carbon capture/storage (called BioCCS or BECCS) led to a negative carbon approach for climate change mitigation [8]. In total, 196 parties adopted the Paris Agreement at the 21st session of the Conference of the Parties (COP21) in Paris, where a post-2020 global action plan on climate change was developed, aiming to enhance capabilities for addressing climate change in the context of sustainable development and poverty eradication [9]. As specified in the Paris Agreement, countries agreed to limit the global temperature rise to 2 °C and work to limit the global temperature rise to 1.5 °C. As of February 2021, 124 countries worldwide have announced their intentions to achieve carbon neutrality and net-zero carbon emissions by 2050 or 2060 [10]. Chen et al. (2022) presented a strategy to reach a carbon-neutral economy by examining the outcome goals of the 26th United Nations Conference of Parties on Climate Change (COP26), held in Glasgow during 31 October–12 November 2021, and the four main outcome goals of COP26 are to secure global net-zero carbon emissions by mid-century and keep 1.5 °C within reach, adapt to protect communities and natural habitats, stimulate finance, and work together to deliver, focusing on coal, electric vehicles, cash, and trees, respectively [11]. To attain the targets, it is necessary to not only reduce CO_2 emissions, but also to remove CO_2 from the atmosphere. Clearly, green development has been a significant part of global economic reform, and the construction of sustainable ecological civilization has become an important part of the national development strategy. In fact, to achieve net-zero carbon or negative carbon emission measures, it is urgent to achieve the construction of an environmental protection and resource-saving urban system, along with the harmonious development of cities and nature. Green development of cities is imperative [12]. In China, the report of the 19th CPC National Congress proposed to "establish a sound economic system of green, low-carbon and circular development", and the 14th Five-Year Plan (2021–2025) promulgated by the Chinese government specified to continuously improve the quality of the urban environment. As the first country to join PAGE (the Partnership for Action on Green Economy), the Parliament of Mongolia has approved the Green Development Policy (GDP) for Mongolia, which determines goals and objectives for green development, and outlines actions to ensure that these goals are achieved (https://www.un-page.org/mongolia-adopted-action-plan-green-development-policy accessed on 4 April 2022).

At present, global energy is undergoing a low-carbon revolution in fossil energy, a large-scale revolution in new energy, and an intelligent revolution in energy management [13]. Green development is a basic way to replace the traditional development modes and break the constraints of resources and environment, not serving only as a comprehensive description of the green environment concept, but also as a comprehensive concept emphasizing the coordinated development of economy, society, and the environment. It is a development model that aims at efficiency, harmony, and sustainability, and takes into account both economic growth and environmental protection [14]. According to the environmental Kuznets curve, environmental pollution generally goes through a process of first rising and then falling with economic development [15]. Awan (2013) discussed the relationship between sustainable economic development and environmental pollution, arguing that both developed and developing countries will inevitably cause different degrees of damage to the environment in the process of economic development [16]. Based on the concept of "new urbanism", White and Ellis (2007) focused on the connection between sustainability, the environment, and new urban design, emphasizing that the key to the sustainability of "new urbanism" is to strike a balance between economic, social, and environmental concerns [17]. In recent years, concepts such as human wellbeing, social welfare, equity, sharing, and inclusive growth have also been incorporated into the research framework of green development, further expanding the breadth and depth of relevant research [18]. For example, Chen et al. (2018) incorporated haze into the research framework as a new constraint of environmental efficiency, and discovered in a quantitative study that the degree of openness, urbanization, industrial structure, and technological innovation play a positive role in promoting regional green and sustainable development [19]. With China's provincial data from 1999 to 2016 as an example, Zhu et al. (2019) found through empirical research that both industrial structure rationalization and industrial structure upgrading have a positive impact on green development efficiency (GDE), while human capital and opening to the outside have a negative impact on GDE [20]. Sun and Huang (2020) evaluated regional carbon emission efficiency based on panel data of 30 provinces in China from 2000 to 2016, and the empirical results showed that the relationship between urban population and carbon emission efficiency shows an inverted U shape [21].

Existing research on the relationship between urban development and green development provides great theoretical and practical value for high-quality urban development. Nevertheless, it is not sufficient to measure the relationship between urban development and green development from a single perspective such as economic development, industrial structure, or urban population [20,21]. Due to the integrated development of cities, it is necessary to comprehensively measure the development of economy, society, people's livelihoods, planning, and other aspects. For example, how will government planning, science and education levels, and other urban development factors affect green development? Moreover, most empirical studies focus on green development at the provincial level, and there are few evaluations of green development at the municipal level [22,23]. With the continuous development of China's reform and opening up, the Chinese government has proposed a major national economic development strategy for integrated development of the Yangtze River Delta, and the Yangtze River Delta urban agglomeration has become one of the most representative areas in China [24]. To fill the above gap, the efficiency of urban green development in the Yangtze River Delta was evaluated in this paper based on panel data, and the regression model was applied to comprehensively analyze the impact of urban development on the green development level, so as to study how to make urban development plans to improve the green development level and make suggestions for high-quality urban development.

The rest of this paper is organized as follows: The variable selection, data sources, and research area are listed in Section 2; the research method and the results of empirical analysis are shown in Section 3; the discussion is presented in Section 4; and all contents are concluded in Section 5.

2. Materials and Methods

2.1. Description of Variables

2.1.1. GDE Variables

In this paper, based on the previous research, corresponding indices—including annual electricity consumption (I1), investment in fixed assets (I2), and persons employed in the management of water conservancy and the environment (I3)—were selected as the input indices of green development from the perspectives of labor, capital, and energy [20]. The industrial wastewater discharge (O1) and industrial sulfur dioxide production (O2) were selected as the undesirable output indices and the gross regional product (O3) was used as the desirable output index [25].

2.1.2. Urban Development Variables

Under the comprehensive consideration of the impact of urban development on green development and the existing evaluation of urban development [26,27], the following influential factors were selected in this paper:

(1) Economic factors (U1): The total retail sale of consumer goods (RSCG) indicates the economic development. According to the environmental Kuznets curve (EKC), it is confirmed that there is a certain correlation between economic development and the environment [15,28].
(2) Innovation level (U2): The expenditure for education, science, and technology (EEST) indicates the levels of science and education. A high level of innovation can promote the circular economy of cities and protect the environment to some extent [29].
(3) Urban construction (U3): The area of built districts (ABD) represents urban construction. Faced with the expansion of construction land, the corresponding pollution may have a certain impact on the environment.
(4) Government planning (U4): The green-covered area of built-up area (GACA) is a result of government planning. As one kind of environmental regulation, better green development may be achieved for cities by attaching importance to the investment and planning of green land.
(5) Other control variables: The industrial structure (C1) and urbanization level (C2). Tertiary industry's share of GDP (TGDP) refers to the industrial structure, and the urbanization rate (UR) stands for the urbanization level. Many studies have found that industrial structure and urbanization levels have an impact on green development efficiency [20,21,30]. The above input, output, and urban development indices are summarized in Table 1.

Table 1. Evaluation indices.

Vector	No.	Index	Unit
Input Index	I1	Annual electricity consumption	10,000 kwh
	I2	Investment in fixed assets	10,000 RMB
	I3	Persons employed in the management of water conservancy and the environment	Person
Output Index	O1	Industrial wastewater discharge	10,000 tons
	O2	Industrial sulfur dioxide production	Ton
	O3	Gross regional product	10,000 RMB
Urban Development Index	U1	RSCG	10,000 RMB
	U2	EEST	10,000 RMB
	U3	ABD	sq.km
	U4	GACA	Hectare
	C1	TGDP	%
	C2	UR	%

Notes: organized by the authors.

2.2. Research Area and Data Sources

In this paper, the urban agglomeration of the Yangtze River Delta in China was selected as the research object, covering the municipality of Shanghai and Jiangsu, Zhejiang, and Anhui Provinces, with a total area of 358,000 km^2, as shown in Figure 1. Jiangsu Province contains the cities of Nanjing, Wuxi, Xuzhou, Changzhou, Suzhou^1, Nantong, Lianyungang, Huai'an, Yancheng, Yangzhou, Zhenjiang, Taizhou^1, and Suqian. Zhejiang Province consists of the cities of Hangzhou, Ningbo, Huzhou, Jiaxing, Shaoxing, Wenzhou, Quzhou, Lishui, Taizhou^2, Jinhua, and Zhoushan. Anhui Province covers the cities of Hefei, Wuhu, Bengbu, Huainan, Maanshan, Huaibei, Tongling, Anqing, Huangshan, Fuyang, Suzhou^2, Chuzhou, Lu'an, Xuancheng, Chizhou, and Bozhou.

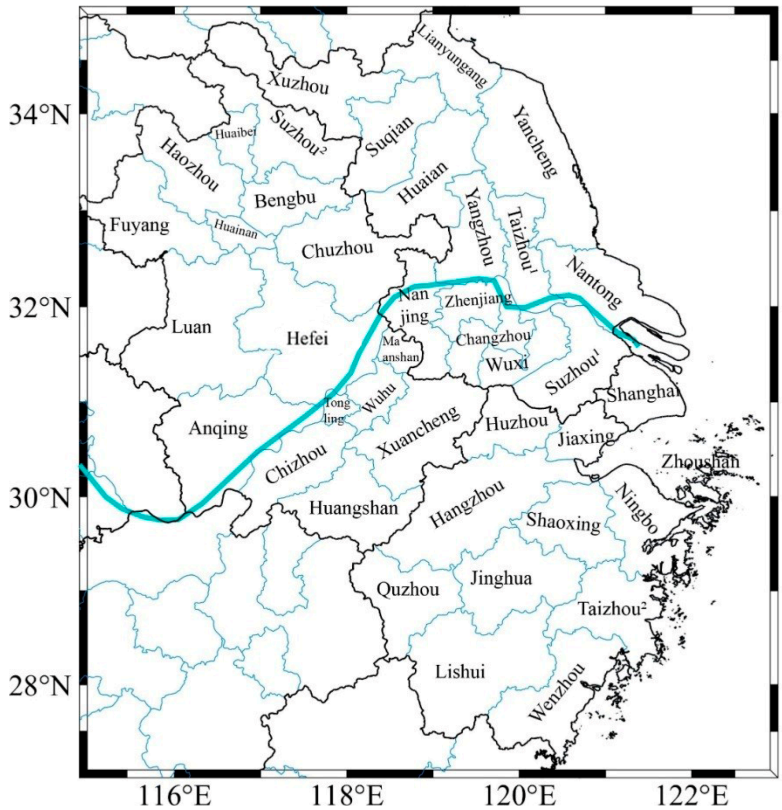

Figure 1. Administrative districts of 41 cities in the Yangtze River Delta (Suzhou[1] and Taizhou[1] are the cities in Jiangsu Province. Suzhou[2] and Taizhou[2] belong to Anhui and Zhejiang provinces, respectively). Note: the figure was made by the authors.

In total, 41 cities in the Yangtze River Delta were mainly studied, over a research period of 10 years (2009–2018). The research data were obtained from the *China City Statistical Yearbook for Regional Economy* (2009–2018), and some data were collected pursuant to the statistical yearbooks of provinces (municipalities) and the statistical bulletins of relevant municipalities on national economic and social development. The "denotation" or "mean value" method was adopted to calculate the missing data according to the actual situation. Table 2 presents the descriptive statistics of the variables.

Table 2. Descriptive statistics of the variables.

Variable	N	Mean	STD.	Min.	Max.
I1	410	1.828×10^6	3.031×10^6	67,166	3.182×10^7
I2	410	2.173×10^7	1.806×10^7	2.352×10^6	1.124×10^8
I3	410	9873	12,761	455	93,600
O1	410	11,624	13,123	486	80,468
O2	410	43,067	45,387	1407	496,377
O3	410	3.578×10^7	4.420×10^7	1.331×10^6	3.268×10^8
U1	410	1.354×10^7	1.690×10^7	791,784	1.267×10^8
U2	410	1.022×10^6	1.572×10^6	64,104	1.344×10^7
U3	410	176.5	186.4	31	1238
U4	410	7925	10,934	1256	139,427
C1	410	0.420	0.0825	0.234	0.793
C2	410	0.587	0.123	0.291	0.896

Notes: organized by the authors.

2.3. Description of Calculation Modes

2.3.1. Super-SBM Model

The traditional data envelopment analysis (DEA) method assumes that the output is maximized, which is not applicable to a situation where waste gas, wastewater, and other undesirable outputs are produced in the production process [31]. As a result, Tone (2001) proposed an SBM model with undesirable outputs taken into account [32]. For the SBM model, a non-radial and non-angular DEA analysis method was proposed on account of slack variables [33], which can eliminate the deviation and influence caused by the differences in radial and angle selection, since the efficiency value changes exactly with the change in the degree of input–output slack. Nonetheless, the efficiency measured by the SBM model is incapable of evaluating and ranking the decision-making units at the frontier boundary of efficiency [33]. Consequently, Zhang et al. (2017) further improved it into a Super-SBM model considering undesirable outputs [34]. The Super-SBM model was applied in this paper to measure urban GDE. According to Tone (2002), it was assumed that there were n decision-making units (DMUs), and each unit contained three factors constituting the production frontier, including inputs, desirable outputs, and undesirable outputs [33]. For each DMU, m input factors were used to produce s_1 desirable outputs and s_2 undesirable outputs, and relevant factors were denoted by the three vectors $x \in R^m$, $y^d \in R^{s_1}$, and $y^{ud} \in R^{s_2}$. The matrices X, Y^d, and Y^{ud} were defined as follows:

$$\begin{aligned} &X = [x_1, x_2, \ldots, x_n] \in R^{m\times n}, Y^d = \left[y_1^d, y_2^d, \ldots, y_n^d\right] \in R^{s_1\times n}, \\ &Y^{ud} = \left[y_1^{ud}, y_2^{ud}, \ldots, y_n^{ud}\right] \in R^{s_2\times n}. \end{aligned} \tag{1}$$

Assuming that $X > 0, Y^d > 0, Y^{ub} > 0$, the production possibility set (PPS) can be described as follows:

$$P(x) = \left\{ \left(y^d, y^{ud}\right) \middle| x\ produce \left(y^d, y^{ud}\right), x \geq X\lambda, y^d \leq Y^d\lambda, y^{ud} \geq Y^{ud}\lambda, \lambda \geq 0 \right\} \tag{2}$$

where λ is the non-negative intensity vector. The three inequalities in the PPS indicate that the actual input level is not lower than the frontier input level, the actual desirable output level is not higher than the frontier desirable output level, and the actual undesirable output level is not lower than the frontier desirable output level, respectively. Assuming that $DMU_k\left(x_k, y_k^d, y_k^{ud}\right)$ is SBM-efficient, according to Zhang et al. (2015), the Super-SBM model with undesirable outputs can be measured as follows [34]:

$$\begin{aligned} &\beta_{SE} = \min \frac{1 + \frac{1}{m}\sum\limits_{i=1}^{m} \frac{s_i^-}{x_{ik}}}{1 - \frac{1}{s_1+s_2}\left(\sum\limits_{r=1}^{s_1} \frac{y_r^d}{y_{rk}^d} + \sum\limits_{t=1}^{s_2} \frac{y_t^{ud}}{y_{tk}^{ud}}\right)} \\ &s.t.\ x_i^k \geq \sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^- \\ &y_{rk}^d \leq \sum_{j=1, j\neq k}^{n} y_{rj}^d\lambda_j + y_r^d \\ &y_{tk}^{ud} \geq \sum_{j=1, j\neq k}^{n} y_{tj}^{ud}\lambda_j + y_t^{ud} \\ &1 - \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} \frac{y_r^d}{y_{rk}^d} + \sum_{t=1}^{s_2} \frac{y_t^{ud}}{y_{tk}^{ud}}\right) > 0 \\ &\lambda, s^-, s^+ \geq 0 \\ &i = 1, 2, \ldots, m; j = 1, 2, \ldots, n(j \neq k)\ r = 1, 2, \ldots, s_1;\ t = 1, 2, \ldots, s_2 \end{aligned} \tag{3}$$

where β_{SE} is the value of super-efficiency of the DMU k's, while s^{-}, y^{d}, and y^{ud} denote the slacks of inputs, desirable outputs, and undesirable outputs, respectively. If $\beta_{SE} \geq 1$ and $s^{-} \geq 0$, $y^{d} \geq 0$, $y^{ud} \geq 0$, the DMU is SBM-efficient. If $\beta_{SE} < 0$, the DMU is relatively inefficient, and the inputs and outputs should be improved.

2.3.2. Tobit Regression Model

Although the Super-SBM model can be used to analyze the level of and change in GDE from both static and dynamic perspectives, the GDE value measured by the Super-SBM model cannot be negative, with zero as the lower limit [35]. To identify the effectiveness of urban development, a Tobit regression model that estimates parameters via maximum likelihood estimation (MLE) was used to solve this kind of restricted dependent variable problem [36]. The basic form of the Tobit model is as follows:

$$Y_{kt} = \begin{cases} Y^{*}_{kt} = \alpha + \beta X_{kt} + \varepsilon, & Y^{*}_{kt} > 0 \\ 0, & Y^{*}_{kt} \leq 0 \end{cases} \tag{4}$$

where Y_{kt} is the truncated dependent variable of the decision-making unit k in period t (i.e., the GDE value of the city k_{th} in period t), Y^{*}_{kt} indicates the latent variable of the decision-making unit k in period t, and X_{kt} stands for the independent variable, which is used for the selection of urban-development-influencing factors.

In this study, a Super-SBM was proposed, and Tobit regression analysis was applied to explore the effects of urban development on GDE, which was mainly carried out via two steps: GDE measurement, and impact analysis of urban development on GDE, as shown in Figure 2.

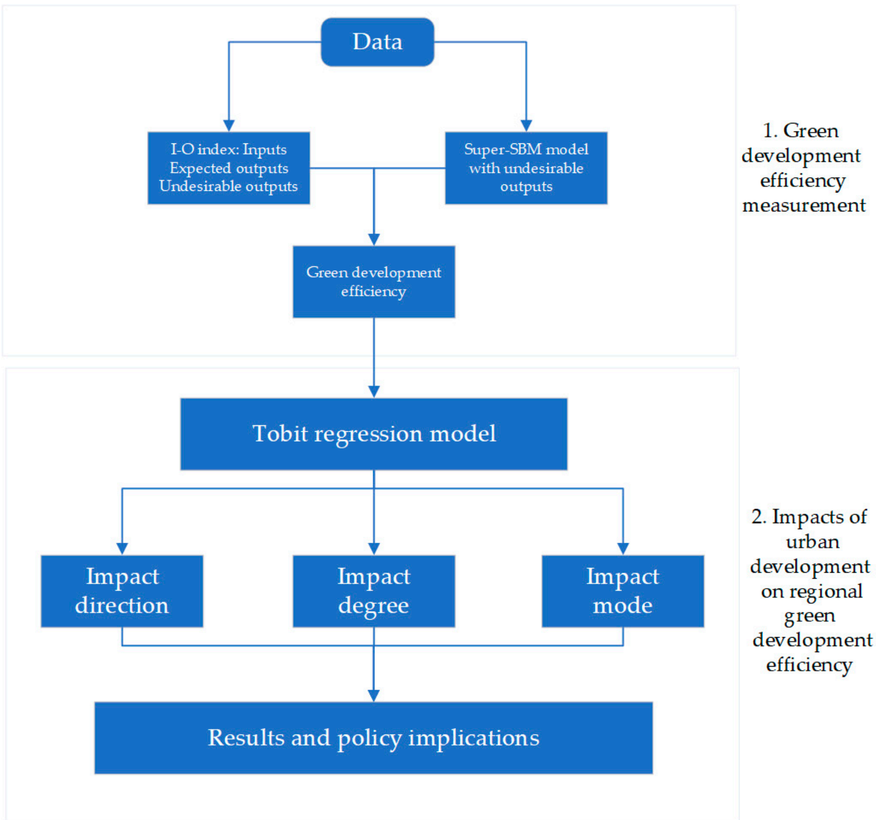

Figure 2. Exploration of the links of impacts of urban development on GDE. Note: the figure was made by the authors.

3. Results

3.1. GDE

The Super-SBM efficiency model was established using DEA-SOLVER Pro5. The GDE of 41 cities in the Yangtze River Delta is shown in Table A1 in Appendix A.

According to Table A1, it is obvious that the GDE of the 41 cities can be effectively ranked by the proposed Super-SBM model. In this regard, the city of Huaibei exhibited the largest GDE value, averaging 1.296, followed by Huangshan, while the mean GDE of nine cities exceeded 1. Three cities had a mean GDE of less than 0.5, and Huainan had the lowest GDE of 0.511. Overall, the mean GDE in the Yangtze River Delta during 2009–2018 was 0.824, showing fluctuating growth trends in most cities and tending to be stable. In terms of changes in the average annual growth rate, Huangshan had the highest score of 20.19%, followed by Zhoushan and Chizhou (over 15%), while Fuyang obtained the lowest score of −5.34%.

According to the above, Figure 3 displays the spatial heterogeneity of mean GDE in the Yangtze River Delta from 2009 to 2018. The GDE was relatively low in most cities of the northern part of the Yangtze River Delta except for Huaibei, and there was an increasing trend from the northwest to southeast coastal areas in the Yangtze River Delta. In addition to the economically developed cities such as Suzhou and Shanghai, Huangshan, Xuancheng, and Quzhou all achieved relatively high GDE, presenting an agglomeration effect in the middle of the whole region.

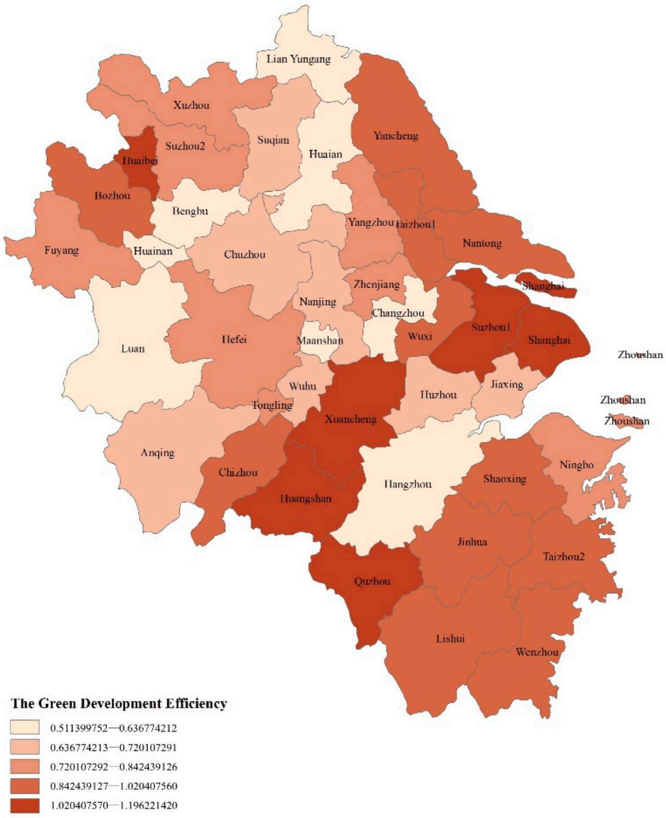

Figure 3. Geospatial distribution of 10-year mean GDE in the Yangtze River Delta. Note: the figure was made by the authors.

At the provincial level, as shown in Figure 4, the line chart of the annual GDE value calculated by the Super-SBM model reflects the trend of efficiency over time in four provinces. In the last decade, the GDE value showed ansan upward trend from 2009 to 2012 in Jiangsu Province and a downward trend from 2016 to 2018 in Zhejiang Province, fluctuating around 0.8 in Jiangsu, Zhejiang, and Anhui Provinces. In the meantime, the municipality of Shanghai experienced two growth periods from 2009 to 2012 and from 2016 to 2017. Shanghai, whose GDE was once at the lowest level of 0.616, jumped to the leading position, and the gaps between Shanghai and the three aforementioned provinces gradually widened.

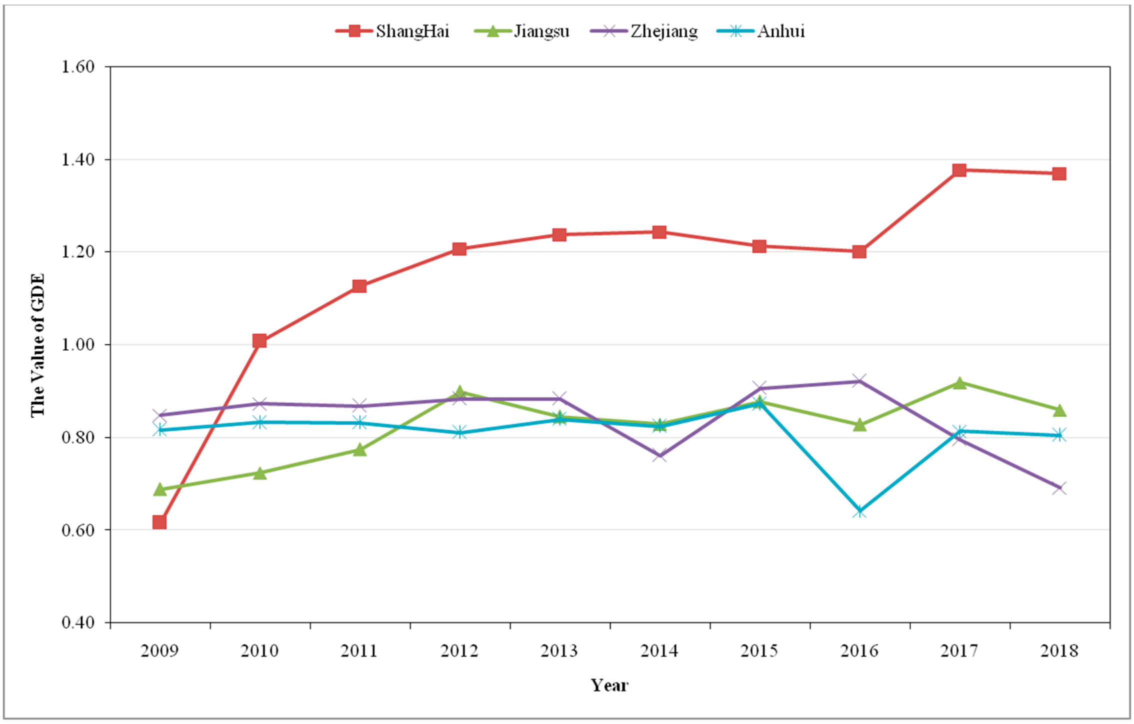

Figure 4. Average annual GDE of 4 regions in the Yangtze River Delta. Note: was once at the lowest level of 0.

3.2. Analysis of the Impact of Urban Development on GDE

The software Stata was used to establish a Tobit model for regression of the relationship between urban development and GDE. The results are shown in Table 3.

Table 3. Tobit regression results with full sample.

Variable	Model	
	Model 1	**Model 2**
RSCG (U1)		0.636 * (1.87)
EEST (U2)		0.574 ** (2.26)
ABD (U3)		−1.915 *** (−4.46)
GACA (U4)		0.915 ** (2.56)
TGDP (C1)	0.292 *** (3.85)	0.214 ** (2.30)
UR (C2)	−0.114 * (−1.65)	−0.038 (−0.46)
Cons	0.767 *** (25.86)	0.780 *** (21.25)
Log-Likelihood	−48.224	−26.523
LR chi^2 (n)	15.00	58.40
Prob > chi^2	0.0006	0.0000
Pseudo-R^2	0.1346	0.5240

Notes: *, **, and *** represent significance levels under 10%, 5%, and 1%, respectively. RSCG, EEST, ABD, and GACA represent 4 explanatory variables. TGDP and UR represent 2 control variables, and Cons represents a constant term.

Model 1 comprised the regression equations of independent variables containing only control variables C1 and C2 to GDE. Model 2 added the explanatory variables on the basis of Model 1. The results of the models showed that the p-values of the likelihood ratio test were $0.0006 < 0.05$ and $0.0000 < 0.05$, respectively, denoting that the addition of the explanatory variables is helpful to the model, and the square of pseudo-R in Model 2 is 0.5240, which means that the explanation of the four explanatory variables for the GDE is 52.40%. It can be seen that both C1 and C2 can pass the significance test when introduced into regression Model 1, and C1 can pass the significance test while C2 cannot when they are introduced into regression Model 2. For cities in the Yangtze River Delta, RSCG had a significant positive effect on GDE (Coef. = 0.636), meaning that the higher the total retail sales of consumer goods, the higher the efficiency of green development. EEST was positively correlated with GDE (Coef. = 0.574); that is, this variable played a promoting role. The coefficient of ABD in the model was −1.915. It is recommended that the area of built districts inhibits the improvement of the GDE. The parameter estimation value of the GACA in the model was 0.915, suggesting that the green-covered area of complete area is a positive incentive factor.

3.3. Robustness Tests

As stated above, we propose a novel integrated-approach super-efficiency SBM with undesirable outputs and Tobit regression analysis to explore the effects of urban development on GDE. In order to verify the accuracy of these conclusions, it is necessary to analyze their robustness.

In this study, winsorization was performed on the main continuous variables at the 5% level, and ordinary least squares (OLS) was used to re-estimate the regression equations. As shown in Table 4, RSCG, EEST, and GACA had positive effects on GDE, while ABD had a significant negative effect on GDE. The results of OLS regression are consistent with Tobit regression, as shown in Table 4. In summary, the robustness tests show that the results obtained are robust and reliable.

Table 4. Robustness test results.

Variable	Model	
	Model 1	Model 2
RSCG (U1)		0.6491939 ** (1.99)
EEST (U2)		0.5516435 ** (2.28)
ABD (U3)		−1.787332 *** (−3.94)
GACA (U4)		0.816832 ** (2.07)
TGDP (C1)	0.2765065 *** (3.8)	0.1836616 ** (2.01)
UR (C2)	−0.1033908 (−1.59)	−0.0346601 (−0.44)
Cons	0.7350799 *** (17.06)	0.7804275 *** (21.25)
Prob > F	0.0217	0.0000
R^2	0.0541	0.1600

Notes: ** and *** represent significance levels under 5% and 1%, respectively, while C is a constant term.

4. Discussion

4.1. Information on GDE

At present, the calculation and evaluation of GDE in China are mostly concentrated at the provincial level, or mainly focus on key cities with high administrative levels, such as municipalities and provincial capital cities. Zhang et al. (2017) studied the green ecological efficiency of 105 key cities in China, and concluded that cities in Central and Western China relied more on traditional production factors such as natural resources to drive economic growth, limiting the green development of cities [37]. China's Green Development Report pointed out that eastern cities have a higher level of economic development, while central and western cities have a larger resource- and environment-carrying capacity [12]. According to the research in this paper, Shanghai performed better than the other three provinces, and its GDE was significantly superior to that of the other provinces after a series of rises, despite its GDE being the lowest in 2009. This result is similar to the results of Chen et al. (2019), who calculated the total-factor eco-efficiency (TFEE) and illustrated that Shanghai enjoyed more stable growth of TFEE than the other three provinces [38]. In addition, with a significant role in promoting economic and social development, the effect of mega-events draws the attention of countries and regions around the world [39,40]. In 2010, with "city" as the theme, the Shanghai World EXPO exchanged and promoted the concept of sustainable urban development, successful practice, and technological innovation, which strengthened the urban environmental awareness and understanding of positive urban development.

Admittedly, municipalities and large cities (i.e., Suzhou[1] and Shanghai in this paper) enjoy rich resource bases, advanced technology platforms, and personnel allocation due to their high administrative levels, guaranteeing the transformation efficiency of output results, and these advantages strongly promote green development in large cities [37]. In this study, coastal cities and cities in the southeast under the background of a relatively developed economy showed higher levels of GDE compared with inland cities in the northern part of the Yangtze River Delta. However, some provincial capitals, such as Nanjing and Hangzhou, have not achieved satisfactory results in GDE. The urban construction in these big cities is in full swing—especially the property market, which has heated up dramatically since 2015, leading to the rise of urban reinforced concrete forest, followed by more construction waste, hindering the benign expansion of green space. Not only the importance of inputs, but also the rationality of outputs, should be taken into account for GDE. Large cities often have redundant inputs and relatively insufficient outputs in the case of lack of flexibility [41].

Some overlooked prefecture-level cities, such as Huaibei and Huangshan, stand out in terms of GDE performance, because their economic development relies on tourism or the service industry instead of industries characterized by resource consumption and pollution, and the high flexibility of small cities ensures the efficiency of their outputs. It is worth noting that several cities in the middle of the Yangtze River Delta (i.e., Xuancheng, Huangshan, and Quzhou) showed relatively high GDE and presented agglomeration effects. These cities are located in mountainous areas with beautiful natural scenery and few industries characterized by high pollution, high consumption, and high emissions, so it is natural to develop tourism and service industries to support their local economies, resulting in high GDE. The characteristic terrain affects the industrial characteristics, thus affecting the local green development. From this point, it can also be seen that the urban development factors that affect GDE should be considered comprehensively from many perspectives.

4.2. Impact of Urban Development on GDE

4.2.1. Economic Development

Economic development has always been an important factor affecting the green environment. Many studies have confirmed that the main driving force for the improvement of regional eco-green coordinated development is high-quality economic development [21,42,43]. The empirical results of this paper show that economic development has a significant positive impact on green development, which supports the previous views. According to the environmental Kuznets curve, with the development of the economy, environmental pollution generally experiences a process of first rising and then falling [15]. Feng et al. (2017) also proved that there is a U-shaped environmental Kuznets curve between GDP and the green development level [28]. The possible reason lies in the different indices selected for economic development. RSCG selected in this paper represents the consumption capacity of urban residents, which can also reflect the economic development level of the city from the perspective of people's livelihoods. Therefore, urban economic indices should be considered more comprehensively when measuring the relationship between economic development and green development. As shown in Figure 3, some economically developed areas—such as coastal areas—indeed presented higher GDE, which may result from the fact that the developed economic environment can attract more capital and high-level talent, and these two factors are also the basis for the development of advanced technologies such as cleaner production [21]. Furthermore, China's economic development has experienced a process from rough expansion based on factor-driven growth to high-quality development driven by innovation, and the influence of economic factors will increase significantly with the further development of the green economy.

4.2.2. Innovation Level

The results of this paper support the point that there is a significant positive relationship between the science and education levels and GDE. The investment in science, technology, and education can be used to measure the innovation level of a city, which is an important basis for the development of urban circular economy [27]. The improvement of innovation levels is of great significance to the improvement of clean production technologies, such as energy-saving and environmental protection technology development, energy consumption reduction, and environmental pollutant discharge restriction. Zhang et al. (2017) demonstrated that innovation input is crucial to urban ecological efficiency, and confirmed that large cities with rich innovation resources and platforms for the transformation of scientific and technological achievements tend to have higher ecological efficiency [37]. According to the calculation results of this paper, green development levels are relatively high in provincial capital cities such as Hefei and Shanghai, and these cities are the centers of science, technology, and culture in their respective provinces. For emerging economies, green innovation facilitates a leap from the high-pollution stage in the early stages of development to the third stage of the environmental Kuznets curve—a low-pollution stage of steady development known as the sustainable development stage [44]. In this sense, cities should pay attention to the development of science, technology, and education, improve the innovation level, and build ecologically sustainable high-quality development cities.

4.2.3. Urban Construction

ABD refers to the area that has been developed and constructed in an urban administrative region and is equipped with municipal public facilities and basic public facilities, including large amounts of asphalt, reinforced concrete, glass, and other basic building materials [45]. The size of ABD, rarely mentioned as an index for measuring urban development in previous studies, measures the status of urban construction, which is the only factor to be significantly negatively correlated with GDE in our empirical results. In the process of urban construction, the green ecology of cities is further destroyed by light pollution, air pollution, and noise due to the accumulation of large amounts of building materials [27]. From the perspective of geographical space, some cities in southwest Anhui Province and west Zhejiang Province are not suitable for large-scale urban construction due to their mountainous terrain, so they often develop tourism and service industries according to local conditions, thereby enjoying relatively high GDE.

4.2.4. Government Planning

Government intervention plays a crucial role in analyzing the institutional conditions for promoting green development [46]. Positive government intervention and planning for green development, such as the promulgation of environmental policies and investment in pollution control, strengthen natural capital and social equity, and avoid high-quality urban development at the expense of the environment. As one kind of green infrastructure investment, GACA has always been the focus of government planning [27]. The results in this paper show that the larger the GACA, the higher the GDE, which has rarely been mentioned in previous research. Most indices of government intervention are about economic structure, policy orientation, and macro-control, as well as incentive mechanisms [21,46], while the green-covered area reflects the government's investment in green development more intuitively. As government planners become increasingly aware that the dynamics of urban green-covered area have become an important topic in the discourse of sustainable urban development [47], the central and local governments have issued many policies on urban greening, such as the Regulations of China on Urban Greening, Shanghai Greening Regulations, Special Planning of Hefei Urban Green Space System (2020–2035), etc. Cities with strong economic development capacity often tend to pay more attention to green planning and introduce relevant policies and regulations. Pang et al. (2019) explained that the threshold of economic development, with per capita GDP of about RMB 90,000, is the turning point when local governments change focus, which means that with economic development, local governments' plans to improve the environment will gradually increase [48]. Similarly, in this paper, some cities with good economic development—such as Shanghai, Suzhou, Nanjing, and Hefei—were more willing to make plans in green space construction to achieve higher GDE. A better foundation for urban expansion planning can be laid in combination with the negative correlation between ABD and GDE mentioned above, and the government may attach more importance to the rational investment and distribution of the urban green-covered area in the urban construction expansion process, so as to protect the sustainable ecological environment of cities.

4.2.5. Other Factors

Industrial structure adjustment is one of the effective measures to achieve green development [20]. Therefore, how to improve GDE through industrial structure adjustment has become one of the hot issues in the fields of energy, environment, and economy. The results of this paper show that the higher the proportion of tertiary industry, the greater the efficiency of urban green development, which fully indicates the importance of optimizing industrial structure for green development. Many studies indicate that the higher the proportion of tertiary industry, the better the ecological environment [19,20]. Guo et al. (2020) explained that the higher the proportion of secondary industry, the less conducive it is to green development, which is consistent with the results of this paper [43]. According to China's 13th Five-Year Plan for National Economic and Social Development (2016–2020), green development can be achieved through industrial restructuring.

In the process of high-quality urban development, it is suggested that the industrial structure of all cities should be adjusted reasonably, the proportion of the secondary industry characterized by high pollution, high consumption, and high emissions should be reduced gradually, and the service and business model innovation should be implemented to drive the development of the productivity model, so as to realize industrial structural optimization step by step.

In this paper, the proportion of urban population to total population (i.e., the urbanization rate) was selected as an index to measure the level of regional urbanization [26]. There was no significant correlation between urbanization and GDE, which may indicate that with the increase in the population, there is no clear contradiction between the economic effects brought by demographic dividends and the environmental damage under population pressure. All aspects of urban development were taken into account for urbanization consisting of population structure. The increase in the urban population is conducive to capital flow, which strengthens economic development, knowledge spillover, and technological progress, thereby improving GDE. On the other hand, the expansion and high concentration of the urban population lead to a series of problems such as land expansion, vegetation destruction, and energy consumption caused by industrial development, further reducing the environmental quality [21].

It is notable that there has always been controversy about the relationship between urbanization levels and green development. Some scholars believe that urbanization has a significant positive impact on GDE, and that the concentration of the population and economic activities in cities and towns will bring positive impacts such as reduced transaction costs and economies of scale [19]. Deng et al. (2010) believed that urbanization enables industrial structure upgrading, ecological environment changes, and economies of scale, while excessive urbanization will seriously damage the sustainable development of society and the ecosystem, showing an inverted U-shaped relationship between urbanization levels and green development [49]. Song et al. (2015) believed that positive urbanization brings expansion of human activities, which is unfavorable for the restoration of the ecological environment [50]; that is, with the rapid growth of urban population, the demand for transportation and electricity intensifies the externality of urban pollution [51].

This difference mainly results from different interpretations of the term green development in different studies—especially different index composition. How to accurately describe the relationship between urbanization and green development is a key problem to be solved in future research.

5. Conclusions

In this paper, based on the panel data of cities in the Yangtze River Delta of China from 2009 to 2018, the GDE of each region was measured by the super-efficiency SBM model with undesirable outputs. Afterwards, the comprehensive influence of urban development on GDE was empirically studied by Tobit regression analysis. The conclusions are as follows:

Firstly, the GDE of Jiangsu, Zhejiang, and Anhui Provinces in the Yangtze River Delta fluctuated during the research period, but it was on the rise in the municipality of Shanghai. Secondly, the green development was unbalanced, and there was spatial heterogeneity. The GDE of coastal cities and cities in the southeast of the Yangtze River Delta was generally higher than that of cities in the north. Cities in the middle of the Yangtze River Delta showed relatively high GDE and presented agglomeration effects. Our results provide a reference trend for green development in the Yangtze River Delta, as well as a valuable reference for sustainable development and policymaking in various regions. Finally, RSCG, EEST, and GACA all had a positive impact on GDE, meaning that urban economic development, innovation levels, and government planning play significant roles in promoting urban green development. The expansion of urban construction area hinders the improvement of GDE. Based on the findings of this paper, some policy implications can be proposed, as follows:

First of all, for the development of the Yangtze River Delta, the heterogeneity of green development in different regions should be taken into account, and targeted policies and measures should be formulated to stimulate green development. Cities with high GDE should give full play to the exemplary and leading roles in supporting cities with low GDE in industrial transfer and environmental protection, so as to achieve regional ecological win/win and gradually narrow the gaps between different regions. Cities located in the western and northern regions should pay attention to economic development while strengthening the protection of green ecological systems. The coastal and large cities should ensure rational resource allocation to avoid redundant and inefficient outputs.

Second, cities should fully understand the profound significance of scientific and technological innovation, and set up a high-quality mode of economic development. On this basis, the governments should strengthen education investment and improve the quality of residents and the degree of community civilization on the one hand, and speed up the industrial structure adjustment and upgrading on the other hand. Cities need to gradually eliminate low-end industries with high pollution, high consumption, and high emissions, develop high-end industries and services with zero pollution, low consumption, and zero emissions, and develop a green mode of production as soon as possible.

Third, in the process of urban expansion and construction, the government should fully recognize the significance of green space planning in urban ecological civilization construction, avoid vegetation destruction and water conservation capacity reduction caused by blind land expansion, increase investment in urban green spaces, advocate the development of green emerging industries beneficial to urban ecological construction, strengthen the protection of urban green spaces, advance the comprehensive utilization of resources, and strengthen the development of a recycling system for renewable resources.

Constrained by research methods, there are still some limitations to this study, and future research can be further supplemented from the following perspectives: The cities used as samples in the Yangtze River Delta are underrepresented and not informative, so future studies may cover all cities in China. In this study, the relationships between GDE and the economic development, innovation levels, urban construction, and government planning were considered, but a set of indicators were employed only in a simple dimension. For example, the level of economic development can also be represented by per capita GDP [52], and the level of innovation also involves the number of invention patent authorizations [53]. Future research should aim to explore more factors contributing to urban development.

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Appendix A

Table A1. GDE of 41 cities in the Yangtze River Delta.

City	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean Value	Average Annual Growth Rate
Shanghai	0.616	1.007	1.127	1.207	1.238	1.244	1.213	1.202	1.377	1.369	1.160	10.34%
Nanjing	0.468	0.488	0.527	0.576	0.666	0.617	0.763	0.684	0.998	0.774	0.656	7.40%
Wuxi	0.796	0.793	0.849	1.077	1.122	0.919	1.064	1.060	1.197	0.982	0.986	3.33%
Xuzhou	0.564	0.528	0.552	1.642	0.659	0.498	0.695	0.841	0.785	0.748	0.751	4.67%
Changzhou	0.557	0.526	0.548	0.607	0.670	0.546	0.702	0.625	0.833	0.756	0.637	4.77%
Suzhou[1]	1.106	1.149	1.212	1.034	1.013	1.067	1.108	1.162	1.114	0.797	1.076	−2.88%
Nantong	0.774	0.803	0.788	1.087	0.928	0.675	1.010	1.016	1.005	0.869	0.896	3.73%
Lian Yungang	0.522	0.557	0.599	0.615	0.676	0.508	0.679	0.709	0.611	0.586	0.606	2.47%
Huaian	0.425	0.392	0.502	0.532	0.618	0.587	0.699	0.604	0.761	0.813	0.593	8.42%
Yancheng	1.021	1.021	1.035	1.041	1.222	1.447	0.863	0.894	0.776	0.767	1.009	−1.49%
Yangzhou	0.760	0.803	0.791	0.780	0.592	0.833	0.907	0.833	1.009	1.060	0.837	5.15%
Zhenjiang	0.632	0.629	0.672	0.746	0.790	0.859	0.823	0.783	0.829	0.791	0.755	2.71%
Taizhou[1]	0.828	0.855	0.969	0.988	0.991	1.017	1.055	0.985	0.874	1.045	0.961	3.00%
Suqian	0.579	0.587	0.668	0.656	0.644	0.791	0.711	0.601	0.692	0.678	0.661	2.43%
Hangzhou	0.552	0.494	0.522	0.558	0.629	0.618	0.681	0.676	0.891	0.648	0.627	2.99%
Ningbo	0.694	0.703	0.766	0.804	0.848	0.564	0.820	0.725	0.819	0.696	0.744	2.10%
Wenzhou	1.181	1.155	0.860	0.901	0.945	0.644	1.022	1.035	0.760	0.639	0.914	−3.61%
Jiaxing	0.476	0.716	0.724	0.729	0.809	0.642	0.793	1.045	0.589	0.567	0.709	5.60%
Huzhou	0.663	0.684	0.705	0.722	0.774	0.307	0.857	0.785	0.677	0.550	0.672	10.42%
Shaoxing	1.123	1.141	1.078	1.086	0.736	0.712	0.753	0.795	0.708	0.654	0.879	−5.10%
Jinhua	1.100	1.099	1.084	1.053	1.098	1.110	1.135	0.849	0.680	0.458	0.967	−8.27%
Quzhou	1.088	0.888	1.056	1.049	1.032	1.066	1.056	1.806	0.854	0.599	1.049	−1.23%
Zhoushan	0.673	0.775	0.716	0.717	0.700	0.673	0.748	0.488	1.027	1.583	0.810	15.83%
Taizhou[2]	0.857	0.897	1.021	1.001	1.001	0.954	1.002	0.927	0.838	0.663	0.916	−2.35%
Lishui	0.925	1.053	1.016	1.102	1.148	1.090	1.100	1.004	0.911	0.554	0.991	−4.26%
Hefei	0.533	0.565	0.588	0.618	0.823	0.509	0.884	0.860	1.082	1.010	0.747	11.15%
Wuhu	0.672	0.583	0.608	0.647	0.668	0.502	0.769	0.694	0.715	0.952	0.681	6.17%
Bengbu	0.575	0.572	0.552	0.558	0.559	0.576	0.749	0.456	0.805	0.697	0.610	6.03%
Huainan	0.540	0.545	0.485	0.532	0.457	0.479	0.492	0.765	0.325	0.495	0.511	4.81%
Maanshan	0.728	0.668	0.561	0.538	0.550	0.347	0.569	0.544	0.569	0.656	0.573	1.81%
Huaibei	0.676	1.162	1.099	1.134	1.048	1.446	1.545	1.171	1.212	1.469	1.196	11.94%
Tongling	1.112	1.009	0.771	0.740	0.715	0.774	0.722	0.689	0.876	1.018	0.842	0.01%
Anqing	0.650	0.712	0.700	0.764	0.740	0.687	0.837	0.656	0.773	0.682	0.720	1.46%

Table A1. *Cont.*

City	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean Value	Average Annual Growth Rate
Huangshan	0.851	0.930	1.051	1.234	1.223	1.494	1.242	0.434	1.402	1.121	1.098	20.19%
Chuzhou	0.630	0.643	0.727	0.681	0.729	0.751	0.875	0.669	0.591	0.565	0.686	−0.46%
Fuyang	1.059	0.817	0.795	0.541	0.813	0.882	0.951	0.737	0.705	0.491	0.779	−5.34%
Suzhou[2]	0.792	0.783	0.770	0.752	0.792	0.783	0.763	0.682	0.766	0.897	0.778	1.69%
Luan	0.715	0.619	0.561	0.647	0.599	1.101	0.552	0.380	0.563	0.435	0.617	1.47%
Bozhou	1.356	1.311	1.182	1.115	1.050	1.026	1.006	0.581	0.897	0.681	1.020	−4.54%
Chizhou	0.795	1.038	1.171	1.149	1.268	1.002	0.891	0.424	1.161	1.112	1.001	15.20%
Xuancheng	1.390	1.362	1.691	1.329	1.402	0.837	1.114	0.532	0.581	0.598	1.084	−4.57%

Notes: organized by the authors.

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