

Article

Technology or Institutions: Which Is the Source of Green Economic Growth in Chinese Cities?

Jing Han ¹, Xi Chen ^{1,*} and Yawen Sun ²

¹ School of Economics and Resource Management, Beijing Normal University, Beijing 100875, China; nkhanj@bnu.edu.cn

² Institute of European Studies of Chinese Academy of Social Sciences, Beijing 100732, China; 201831410001@mail.bnu.edu.cn

* Correspondence: 201931410001@mail.bnu.edu.cn

Abstract: To relax the increasingly tight resource and environmental constraints on development, China needs to follow a pattern of growth that comprehensively encompasses economic growth, environmental protection, and resource conservation, namely, green economic growth. The key to achieving green economic growth is to improve green total factor productivity, of which technological innovation and institutional innovation are the primary driving forces. Based on the panel data of 266 cities in China from 2004 to 2018, this paper first uses the Directional Distance Function and Global Malmquist–Luenberger productivity index to measure the urban green total factor productivity to represent urban green economic growth; then, the impact of technological innovation and institutional innovation on urban green economic growth is studied by using the panel Granger causality test and SYS-GMM dynamic panel model. The results are described as follows: China’s urban green total factor productivity shows an increasing trend from 2004 to 2018, and the average growth rate of green total factor productivity is 3.27%, which is far lower than the average GDP growth rate of 9.14%; both technological innovation and institutional innovation can significantly promote the growth of the urban green economy, but institutional innovation has a greater role in promoting the growth of the urban green economy than technological innovation. In addition, the relationship between institutional innovation and urban green economic growth is more stable.

Keywords: technological innovation; institutional innovation; urban green economic growth; green total factor productivity



Citation: Han, J.; Chen, X.; Sun, Y. Technology or Institutions: Which Is the Source of Green Economic Growth in Chinese Cities? *Sustainability* **2021**, *13*, 10934. <https://doi.org/10.3390/su131910934>

Academic Editor: Luigi Aldieri

Received: 19 August 2021

Accepted: 27 September 2021

Published: 1 October 2021

Publisher’s Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Since China opened its economy, its economic development has been remarkable. China’s economy has maintained a medium to high growth rate, and in 2010, China overtook Japan as the world’s second-largest economy. At the same time, environmental pollution has affected more than 180 prefecture-level and above cities in China, seriously threatening people’s daily life and bringing great challenges to economic growth [1]. The terrible environmental costs of rapid growth have led us to think about the resource and environmental constraints on economic growth. China’s economic development needs to follow a pattern of growth that comprehensively encompasses economic growth, environmental protection and resource conservation, namely, green economic growth. However, the structural contradictions of China’s economy are prominent and the ability for sustainable development is weak [2]. The obstacles to realising green economic growth are mainly two. (1) First, the growth of the green economy faces some technical obstacles. The proportion of green technology patents in China is not high [3]. By the end of 2017, the number of green patents in China was 136,124, accounting for only 6.5% of the total number of patents in China. Additionally, Beijing was the city with the largest number of green patents at 10,829, accounting for only 2.4% of the total number of patents in Beijing. Another technical hurdle relates to the difficulties in the process of acquiring globally advanced

core green technologies [4]. To avoid the threat of local Chinese enterprises to their vested interests, some multinational companies that have mastered green core technology refuse to share these technologies with Chinese enterprises and have even set impediments to the independent green technology innovation of Chinese firms through their market power. (2) Certain institutional obstacles are the second main set of difficulties faced by the growth of the green economy. First, the endogenous governance system characterised by fiscal decentralisation will lead to the effect of a 'race to the bottom line' [5]. To win in promotion competition, local governments, under the system of fiscal decentralisation, may use their dominant economic position to compete maliciously with other regions, thus forming a development model centred on short-term interests. Second, environmental regulation policies do not always have the expected effect [6]. In some cases, with the intensification of environmental regulations, the costs of pollution control for enterprises also rise rapidly, which leads to a lack of sufficient funds for R&D and innovation. In contrast, the regulation inhibits the green technology innovation of enterprises and reduces the environmental benefits in the production process of enterprises. Third, the market-pricing system of environmental resource prices is relatively lacking [7]. China prefers to use non-market-oriented means to price environmental resources. This kind of price signalling will lead to the sluggishness of the micro-entities of enterprises, resulting in a lack of motivation for enterprises to change their mode of operation or improve their technology, and resulting in low efficiency of energy and resource utilisation. Finally, China's policies for inviting outside investment and foreign trade are not perfect [8]. In the early stage of opening-up, based on international economic circulation, the opening-up policy provided important support for China's economy, but it did not form an effective incentive for the improvement of resource efficiency or environmental performance.

Therefore, to solve the technical and institutional barriers in the process of urban economic green growth, we must adhere to innovation to trigger a comprehensive change in technologies and institutions, effectively reduce the negative impact of economic and social activities on the ecological environment, and greatly improve the speed and quality of economic growth. Based on the above analysis, the objective of this paper is to measure the green economic growth level of 266 cities in China from 2004 to 2018 and to examine the driving effects of technological innovation and institutional innovation on green economic growth. Three following detailed questions need to be solved. The first one is what is the trend of green economic growth in Chinese cities during 2004–2018. The second is what roles do technological innovation and institutional innovation play in urban green economic growth. The last is how should the government make decisions to give full play of technological innovation and institutional innovation in promoting urban green economic growth this research will attempt to provide scientific references.

The rest of this paper is structured as follows: Section 2 will present a literature review. Section 3 will systematically introduce the theoretical model. Section 4 will present the methodology and data used in this paper. The driving effect of technological innovation and institutional innovation on green economic growth will be discussed in Section 5. Section 6 will conclude this study and present policy recommendations.

2. Literature Review

2.1. Measurement of Green Economic Growth

Different from the traditional extensive economic growth, which only considers the input of tangible factors such as labour, capital and economic output, the green economic growth should take into account the input of resource factors and unexpected outputs such as environmental pollution and pursue the maximisation of economic and environmental benefits [9]. The Organization for Economic Co-operation and Development put forward a "Green Growth Strategy" and established a comprehensive green economic growth assessment framework covering the economy, the environment and the society [10]. Li et al. (2010) created the first green economic growth evaluation index system including three first-class indicators: the greening level of economic growth, the carrying potential of

resources and the environment, and support from government policies in China [11]. In contrast to establishing a complete green economic growth index system, more scholars use the perspective of total factor productivity (TFP) to measure green economic growth [12,13]. TFP has long been regarded as an important component of the transformation of economic development from extensive to intensive development, but if we only consider labour, capital and economic output when calculating TFP, we undoubtedly ignore the cost of resources and damage caused to the environment by economic growth, which is biased. Therefore, when measuring green economic growth, we need to take into account the input of resource factors and unexpected outputs correctly; that is, the growth of green total factor productivity (GTFP) is a more accurate way to measure green economic growth [14]. The stochastic frontier production function method, traditional radial and angular DEA models and non-radial and non-angular SBM models are commonly used methods to measure green total factor productivity, but they all have some defects. The stochastic frontier production function method must set a specific form of the production function, which is generally suitable for the production mode of multiple inputs and a single output, so it is weak in the analysis of multiple outputs; traditional radial and angular DEA models cannot effectively deal with unexpected outputs, while non-angular SBM models can solve the problem of unexpected outputs, but the goal of non-angular SBM models is to maximise the inefficiency of input and output, which is contrary to the goal of the maximise the efficiency of input and output [15–17]. Chung et al. (1997) proposed the Directional Distance Function (DDF), which can increase the expected output and reduce the unexpected output within the boundaries of a production possibility set [18]. Table 1 illustrates a list of recent works, where DDF was used to calculate green total factor productivity [9,19–27]. Indeed, DDF provides the possibility of measuring green total factor productivity scientifically and reasonably, which has become one of the main methods of green total factor productivity. From Table 1, we can see that most of the literature on green economic growth focuses on the national, provincial, or industry level, which is too macro to capture more micro-level information, and there are relatively a few studies measuring the green economic growth of all prefecture-level cities in China. So, based on the DDF model for measuring the green total factor productivity of 266 Chinese cities of prefecture-level or above from 2004 to 2018, this paper expands the measurement of green economic growth from the national level, provincial level or industrial level to the city level.

Table 1. Summary of total factor productivity methods with DDF.

Study	Index	Research Objects
Chen & Gollery (2014)	Green total factor productivity	38 industries in China from 1980 to 2010
Pang et al. (2015)	Total factor efficiency	87 countries in the world from 2004 to 2010
Manello (2017)	Efficiency score and total factor productivity growth indexes considering pollution	Firms located in Italy and Germany, operating in the chemical sector
Du et al. (2017)	Environmental productivity performance	Environmental productivity of China's economic zones and provincial regions from 1999 to 2012; Automobile manufacturers' environmental performance from 2005 to 2012.
Xian et al. (2018)	Production and environmental technologies and endogenous efficiency	China's power industry from 2006–2015
Xia & Xu (2020)	Green total factor productivity	Provinces in China from 1997 to 2015.
Liu & Li (2019)	Green total factor productivity	17 provinces and the countries from 2003 to 2016
Wang et al. (2019)	Green productivity growth	OECD industrial sectors
Gao et al. (2020)	Total factor productivity considering carbon emissions	Provinces in China from 2000 to 2017
Lan et al. (2020)	Total factor productivity	36 Chinese cities from 2006 to 2015

2.2. Driving Factors of Green Economic Growth

The World Bank (2012) proposed a framework for the analysis of green economic growth that includes capital, labour, environment and policy to explain the factors that drive green economic growth [28]. A consensus has developed that economic growth in any period cannot be achieved without the inputs of labour, capital, land and other factors and an increase in factor investment promotes continued economic growth only when it can also bring progress in technology [29]. Technological innovation is not only an important driving force of traditional total factor productivity but also the key to promoting green total factor productivity [30,31]. First, technological innovation can increase marginal products and improve resource utilisation in the production process [32,33]. Second, technological innovation can directly improve the ability of pollution treatment and pollution control to minimise the damage caused by pollutants to the environmental system [34,35]. Third, by embracing green technology, cultivating green industry and promoting green energy development, technological innovation can boost urban green economic growth in all directions [36].

While affirming the contribution of technological innovation to green economic growth, the important role of institutional innovation in economic growth cannot be ignored. The new institutional economists, represented by North, proposed that any process of economic growth is carried out against the background of institutional innovation [37]. Therefore, urban green economic growth is no exception. In the process of institutional innovation promoting urban green economic growth, the opening-up system and environmental regulation system are the most representative, which are also research hot spots of many scholars. First, the innovation of the opening-up system not only increases the domestic capital stock but also leads to the steady implementation of advanced cleaner production technologies and environmental protections of foreign enterprises [38,39]. The innovation of the environmental regulation system can directly affect the growth of the green economy through legal means, which is one of the institutions most closely related to green economic growth. By internalising the externality cost of pollution, environmental regulations can control the pollution emission level of enterprises. In the short run, this would undoubtedly increase the cost of enterprises and reduce production efficiency. In the long run, however, strict environmental regulations would force technological innovation, promote production efficiency, compensate for the economic loss of pollution controls and then promote green economic growth [40–43].

2.3. Influencing Factors of Urban Green Economic Growth

As a symbol of human civilisation and social progress, a city is a high gathering place of population, manufacturers, resources, culture, information and other elements in a limited geographical space. The realisation of green economic growth in cities is of great significance to enhance economic vitality and gain ecological wealth [27]. Most of the literature has studied the influencing factors of urban green economic growth. Song et al. (2019) calculated China's green GDP and studied the impact of economic openness on green economic growth. The results showed that economic openness and green economic growth had a non-linear negative U-shaped relation [44]. Lin & Zhu (2019) confirmed the effect of fiscal spending on green economic growth [45]; Sohag et al. (2019) analysed the impact of cleaner energy, technological and militarisation on green economic growth in Turkey. The results showed that technological innovation could foster green economic growth [46]. Cheng et al. (2021) analysed the effect of the Resource-based Cities Plan on green economic efficiency. The results showed that the plan could significantly promote green economic growth in resource-based cities [47]. To sum up, many factors can affect China's green economic growth: economic factors, environmental factors, technical factors, institutional factors and so on [16,34]. The existing literature has the following principal deficiencies. First, with the continuous highlighting of global resource and environmental problems, many scholars regard innovation as an important means to solve the constraints of resources and the environment. However, due to the complexity of green development,

there is not yet a relatively unified theoretical model, especially for the growth of the urban green economy. This will lead to the lack of theoretical support and significance for the econometric model. Second, most of the literature has focused solely on the impact of technological progress or institutional innovation on green economic growth [48,49], while few studies have focused on the comprehensive impact of technological progress and institutional innovation on green economic growth. However, we must note that technological innovation and institutional innovation do not work independently, ignoring the interaction between the two will lead to inaccurate research conclusions and no practical significance [50]. Third, although most of the literature on the institutional innovation of green economic growth focuses on the opening-up system and environmental regulation, the realisation of urban green economic growth requires the role of the entire institutional system, not just the opening-up system and environmental regulation. Fourth, most literature starts from a single factor on the influencing factors of urban green economic growth, but the urban green economic growth must be affected by multiple factors.

Therefore, this study, based on 266 cities above the prefecture-level in China, analyses the mechanism of technological innovation and institutional innovation that promote and contribute to green economic growth. Its marginal contribution lies in the following. First, the endogenous growth model is applied to demonstrate the mechanism and conditions of urban green economic growth. Second, this paper combines technological progress, institutional innovation and urban green economic growth into a unified research framework to discuss the main driving force of urban green economic growth. Third, multidimensional analysis is used to quantise institutional innovation. This paper measures institutional innovation from more dimensions: the fiscal decentralisation system, the environmental regulation system, the resource pricing system and the opening-up system. Fourth, this paper systematically analyses the influencing factors of urban green economic growth.

3. Theoretical Model and Analysis

Aghion & Howitt (1998) [51] introduced environmental pollution and non-renewable resources into the Schumpeter model and posited that the key to sustainable development was to maintain a continuous innovation flow, which was consistent with the historical experience of many industrialised countries and had been confirmed and supported by many scholars [35,52]. Urban green economic growth is an important part of sustainable development. Therefore, this paper argues that Schumpeter's idea of achieving economic growth through "Creative Destruction" has important theoretical reference value for China's urban green economic growth. By systematically bringing the constraints of environmental pollution and non-renewable resources into Schumpeter's endogenous growth model and introducing it into the analysis of urban green economic growth, this paper constructs a theoretical model of innovation-driven urban green economic growth, analysing the possibility and necessary conditions of innovation-driven green economic growth based on this model.

First, we take environmental pollution and non-renewable resource constraints into the simplified model based on the Schumpeter product vertical innovation framework established by Aghion & Howitt and set the final production function as follows:

$$Y = K^\alpha B^{1-\alpha} L^\beta R^\nu z \quad (1)$$

In Equation (1), K is the material capital used to produce intermediate goods i ; B is the intellectual capital used to produce intermediate products i ; L is the quantity of labour supply; R is the stock of non-renewable resource and S is the non-renewable resource extraction flow, that is $\dot{S} = -R$ and the newly exploited resources can be used as production inputs; z is the pollution intensity and environmental pollution P is an increasing function of output level and pollution intensity z , that is $P(Y, z)$. Besides, B^{max} denotes the frontier of production technology, in the long run, there is a strict proportional relationship between production technology frontier and average technical parameters: $B^{max} = (1 + \sigma)B$, that is

$\dot{B} = \sigma\eta nB$, σ represents the rate of innovation flow promoting the technological frontier of the economy, $\sigma\eta$ represents the productivity of the intellectual capital and $L + n = 1$ is the condition of labour clearance.

Second, considering an economic system in which the population is composed of continuous individuals with infinite life and setting the lifetime utility function of an individual:

$$W = \int_0^{\infty} e^{-\rho t} u(c(t), E(t)) dt \quad (2)$$

In Equation (2), ρ is the discount rate, $e^{-\rho t}$ is the discount factor; $c(t)$ is the time trajectory of consumption per person; $u(c(t))$ is the lifetime utility function of an individual and ε is marginal utility elasticity; $E(t)$ is the time trajectory of environmental quality and it is assumed that environmental quality E has an upper limit value, the upper limit of environmental quality can be reached only when production activities are stopped indefinitely, that is $\dot{E} = -P(Y, z) - \theta E$, θ indicating the maximum possible regeneration speed of the environment. When environmental quality is introduced into the theoretical framework of endogenous growth, people's welfare depends not only on the current material consumption flow but also on the quality of the environment, so $u(c(t), E(t))$ is the instantaneous time function.

Based on the above analysis, the optimal growth problem has been transformed into the growth rate of consumption and innovation at any time. Under the constraints of labour market clearing, the maximisation of production and innovation can be expressed by establishing a Hamilton function:

$$H = U(c, E) + \lambda_1 \dot{K} + \lambda_2 \dot{B} + \lambda_3 \dot{E} + \lambda_4 \dot{R} \quad (3)$$

By calculating the first derivative of the control variables c , n , z and R and combining the laws of \dot{K} , \dot{B} , \dot{S} and \dot{E} , we can obtain the following constraints from the equilibrium growth rate of each variable in the steady-state:

$$\left\{ \begin{array}{l} \varepsilon - 1 > 0 \\ \eta\sigma - \rho > 0 \\ (\varepsilon - 1)(\eta\sigma - \rho) < \theta \left[\varepsilon(1 + \omega) + \frac{\omega + \varepsilon}{(1 - \alpha)\gamma} \right] \\ \eta\sigma - \rho < \varepsilon\eta\sigma \end{array} \right. \quad (4)$$

According to Equation (4), when the following conditions are met, innovation can drive urban green economic growth:

First, $\varepsilon - 1 > 0$ This is a necessary condition for the continuous improvement of environmental quality, which means rational consumers will not damage environmental quality below the threshold of an environmental disaster.

Second, $\sigma - \rho > 0$. This condition means that if the productivity of innovation is greater than the discount rate of time, the promotion effect of innovation on green growth can be fully exerted, and then the green economic growth of cities can be realised along the optimal growth path.

Third, $\eta\sigma - \rho < \varepsilon\eta\sigma$. This condition means that the consumption rate of non-renewable resources is negative, which is conducive to the conservation and protection of resources.

Fourth, $(\varepsilon - 1)(\eta\sigma - \rho) < \theta \left[\varepsilon(1 + \omega) + \frac{\omega + \varepsilon}{(1 - \alpha)\gamma} \right]$. This condition means that when the self-purification capacity or regeneration speed of environmental systems to environmental pollutants is large enough, the excessive growth of pollution relative to environmental regeneration capacity can be avoided. (ω represents the social preference for environmental quality).

In summary, although there are resource and environmental constraints, under the condition of steady equilibrium, sustainable economic growth, resource conservation, and

environmental quality improvement can be achieved at the same time; that is, innovation can drive China's urban green economic growth.

4. Methodology and Data

4.1. Method

4.1.1. DDF-GML Model

The Directional Distance Function is a general expression of the radial DEA model. In the Direction Distance Function model, the direction of DMU forward projection can be customised by researchers. In Euclidean space, the direction of projection is determined by the direction vector, which is composed of the input direction vector and output direction vector, which is the main feature of the direction vector model. If there is unexpected output, it can be distinguished in the Direction Distance Function model. Green economic growth takes resources and environmental factors into consideration. Under the consumption of capital, labour, energy and urban economic activities will bring the expected output and unexpected output. Expected output refers to the growth of gross economic output value, while unexpected output refers to the emission of environmental pollutants. Therefore, the Direction Distance Function can be used to calculate the green economic efficiency (GEE) of cities, which is a static efficiency. Green economic growth is a long-term and continuous process. Pastor & Lovell (2005) proposed that the Global Malmquist index can expand the level of green economic growth from static analysis to dynamic analysis and divide the change in green economic growth into the change in technical efficiency (GMLEC) and technology change (GMLTC). Therefore, this paper uses the Direction Distance Function model including unexpected output to calculate green economic efficiency and combines it with the Global Malmquist index to measure the green total factor productivity of cities [53].

4.1.2. Granger Causality Test

Granger and Newbold (1974) proposed the Granger causality test to determine whether the causality between variables in the economic system is from X to Y or from Y to X or bidirectional causality. It was first applied to time series. Hartwig (2010) extended the Granger causality test to panel data on this basis, and the specific model is defined as follows [54,55]:

$$Y_{it} = \gamma + \sum_{m=1}^p \alpha_m Y_{i,t-m} + \sum_{m=1}^p \beta_m X_{i,t-m} + u_i + \varepsilon_{it} \quad (5)$$

Referring to Formula (5), the panel Granger causality model of technological innovation and urban green economic growth in China is established as follows:

$$Y_{it} = \gamma + \sum_{m=1}^{p1} \alpha_m Y_{i,t-m} + \sum_{m=1}^{p2} \beta_m T_{i,t-m} + \varepsilon_{it} \quad (6)$$

In Equation (6), Y_{it} represents the green total factor productivity of cities in China from 2004 to 2018. T is the technological innovation index, m is the lag phase, and $p1$ and $p2$ are the maximum lag phases of green total factor productivity and the technological innovation index, respectively.

In addition, this paper also uses the panel Granger causality test to explore the relationship between urban green economic growth and institutional innovation in China. The specific model is defined as follows:

$$Y_{it} = \gamma + \sum_{m=1}^{p1} \alpha_m Y_{i,t-m} + \sum_{m=1}^{p2} \beta_m S_{i,t-m} + \varepsilon_{it} \quad (7)$$

$$Y_{it} = \gamma + \sum_{m=1}^{p1} \alpha_m Y_{i,t-m} + \sum_{m=1}^{p2} \beta_m FD/ER/RP/OS_{i,t-m} + \varepsilon_{it} \quad (8)$$

In Equation (7), S is the index of institutional innovation. In Equation (8), FD , ER , RP and OS represent the fiscal decentralisation system, environmental regulation system, resource pricing system, and opening-up system, respectively. The meanings of the other variables are the same as those in Equation (6).

4.1.3. Dynamic GMM Model

Panel data is used to analyse individual dynamic behaviour through modelling. Based on the static panel model, if the lag term of the explained variable is regarded as a random explanatory variable, it becomes a dynamic panel model. In the dynamic panel model, the explanatory variables are easily related to the random disturbance term, which leads to the endogeneity problem of the model. At this time, if the traditional estimation method is used, bias and inconsistency of the parameter estimation will occur. Arellano & Bond (1991) proposed the DIF-GMM estimation, and Arellano & Bover (1995) and Blundell & Bond (1998) proposed the SYS-GMM, which solved the above problems well. Furthermore, Monte Carlo simulation experiments and studies by most scholars show that DIF-GMM is more easily affected by weak instrumental variables, while SYS-GMM can better control the endogeneity of the model by increasing the number of instrumental variables [56–58]. Based on the above analysis, this paper uses SYS-GMM to estimate the following models.

$$Y_{it} = \alpha_0 + \omega Y_{it-1} + \alpha_1 T_{it} + \alpha_2 S_{it} + \mu_{it} + \varepsilon_{it} \quad (9)$$

$$Y_{it} = \delta_0 + \gamma Y_{it-1} + \delta_1 T_{it} + \delta_2 FD_{it} + \delta_3 ER_{it} + \delta_4 ER_{it} \times T_{it} + \delta_5 RP_{it} + \delta_6 OS_{it} + \mu_{it} + \varepsilon_{it} \quad (10)$$

In Equations (9) and (10), i represents the city, t represents the year, and Y , T , S , FD , ER , RP and OS represent the urban green total factor productivity, technological innovation, institutional innovation, fiscal decentralisation system, environmental regulation, resource pricing system and opening-up system, respectively. Equation (9) is a basic GMM dynamic panel model, which is used to analyse the relationship between technological innovation, institutional innovation and urban green economic growth. Equations (10) further examine the relationship between technological innovation, different types of institutional innovation and urban green economic growth, add the interaction between environmental regulation and technological innovation to test whether environmental regulation can influence urban green economic growth by promoting domestic technological innovation and add the interaction between the opening-up system and technological innovation to test whether the opening-up system can affect urban green economic growth by promoting domestic technological innovation.

4.2. Data

4.2.1. Dependent Variable

Green total factor productivity (Y) is the only explained variable. This paper takes 2004 as the starting period of the study and measures and analyses the green total factor productivity of 266 prefecture-level and above cities in China from 2004 to 2018 to characterise the level of urban green economic growth based on the DDF-GML model. Among them, the input factor and output factor are two major indicators to measure urban green factor productivity.

1. Input factor index

Labour (L) is represented by the number of employees in each city at the end of the period. Capital (K) is represented by the capital stock in each year estimated for each city, and energy (E) is represented by electricity consumption within the entire city.

2. Output factor index

The expected output is GDP (G), and the unexpected output includes industrial wastewater emissions (W), sulphur dioxide emissions (S) and industrial smoke and dust emissions (D). In addition, the variables related to price are adjusted based on 2004.

Y represents the green total factor productivity. It should be noted that since GTFP measures the growth rate of green total factor productivity, it is necessary to adjust the measured GTFP and its decomposition index to obtain the actual value of GTFP. Referring to the adjustment method of Chen et al. (2016), the actual GTFP is obtained by multiplying the GML index. It is assumed that the GTFP with 2004 as the base period is 1, and the

actual GTFP in 2005 is the base period value of 2004 multiplied by the GML index of 2005 so that the actual GTFP of each year can be derived [59].

Figure 1 reports China's urban green total factor productivity and its decomposition index. Green total factor productivity is a dynamic reflection of urban green economic growth. In the whole research period, the average green total factor productivity of cities is 1.0327, which shows that the actual total factor productivity growth of Chinese cities is 3.27% under the constraints of resources and environment, which is far lower than the actual average GDP growth rate of 9.14%. This also indicates that, to a certain extent, there is a phenomenon of economic growth at the expense of resources and the environment in China's urban economic growth. In different time periods, 2004–2008, 2009–2013 and 2014–2018, the green total factor productivity was 0.9917, 1.0356 and 1.0327, respectively. This means that from 2004 to 2008, China's cities have not yet achieved green economic growth; since 2009, China's economic development model has changed from extensive to intensive. By gradually implementing the concept of green development into practice, green TFP has changed from negative to positive. Furthermore, from the decomposition index of green total factor productivity, we can see that the decline of green total factor productivity mainly comes from the decline of green technology progress, and the improvement of green total factor productivity mainly comes from the rise of green technology efficiency. The reason for this may be that China's economy has not yet achieved the transformation of new and old kinetic energy, so, to a certain extent, it lacks the endogenous technology power of energy conservation and emission reduction, which leads to some backsliding of green technology progress. However, at the same time, the pace of institutional innovation in China is gradually accelerating, which greatly improves organisational efficiency and management ability, bringing about the continuous improvement of green technical efficiency. Thus, China's economy has ushered in an overall improvement of green total factor productivity. Therefore, in the face of increasingly tight resource and environmental constraints, China should not only improve the contribution of green technology efficiency through institutional innovation but also give full play to the driving role of technological progress in the green economic transformation to comprehensively enhance the driving force of urban green economic growth.

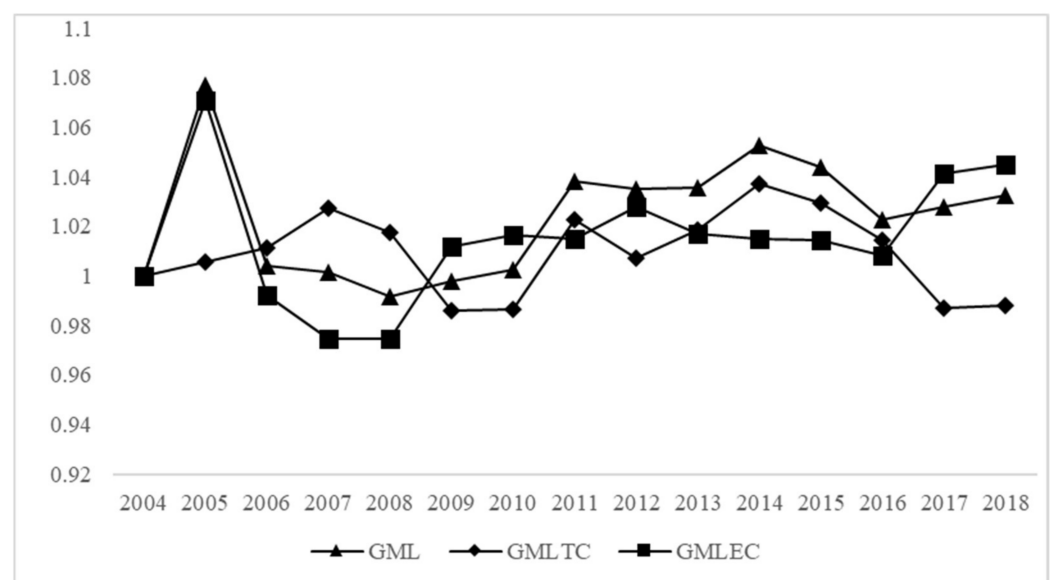


Figure 1. China's urban green total factor productivity and its decomposition index.

4.2.2. Explanatory Variable

1. Technological innovation (*T*)

Most of the existing methods for evaluating technological innovation focus on the selection of macroeconomic indicators related to innovation input and output, and the innovation index is synthesised by either weighing or principal component analysis [60]. However, innovation output is the result of the innovator's input of factors into production; repeated calculations may be a problem when using these two indexes at the same time, resulting in a gap between results and reality. While the number of patents only evaluates the ability of innovation subjects from a single output perspective and based on the openness, objectivity and timeliness of the number of patents, it has become the first indicator of choice for many scholars to measure the level of technological innovation [32–34]. Based on the above analysis, this paper constructs the technological innovation index from the micro perspective and uses the number of green patents granted by each city to represent the technological innovation level of cities.

2. Institutional innovation (*S*)

For the selection index of institutional innovation (*S*), this paper measures the level of institutional innovation from four aspects: fiscal decentralisation system, environmental regulation, resource pricing system and opening-up system by combining with the institutional obstacles in the process of urban economic green growth. Specifically, regarding the fiscal decentralisation system, most of the existing literature uses fiscal revenue decentralisation, fiscal expenditure decentralisation and fiscal share rate to measure fiscal decentralisation. This paper uses expenditure indicators to measure the fiscal decentralisation of each city. Considering the differences in the urban financial management system and to better avoid the impact of population size and central transfer payments on local governments, the calculation of urban fiscal decentralisation is defined as $FD = fdc / (fdc + fdp + fdf)$, where *fdc*, *fdp* and *fdf* represent the per capita fiscal expenditures at the urban, provincial and central levels, respectively [5]. As far as environmental regulation is concerned, based on the research of Zhao et al. (2014), this paper selects the environmental regulation intensity index to characterise environmental regulation [61]. In terms of the resource pricing system, referring to Jia et al. (2014), this paper uses the ratio of government expenditure to fiscal expenditure at the urban level to express the degree of local government intervention in the economy to measure the impact of government intervention on resource allocation and reversely characterises the role of the market in resource pricing [62]. The opening-up system is measured by the proportion of foreign direct investment in GDP in that year. Furthermore, based on fully considering the three attributes of contrast, dispersion and correlation of data, the improved CRITIC method is used to synthesise the above four indicators into the institutional innovation index [63]. (Specific calculation steps can be referred to Appendix A).

L, *K*, *E*, *G*, *W*, *S*, *T*, *fdc*, government expenditure and foreign direct investment were obtained from the China City Statistical Yearbook (2005–2019); *fdp* and *fdc* were obtained from the China City Annual Statistical Report (2005–2019) and the number of green patents was obtained from the National Bureau of Statistics. Furthermore, this paper contains a total of 7 main variables and the descriptive statistical analysis is shown in Table 2.

Table 2. Descriptive Statistical Analysis of the Main Variables.

Variable	<i>Y</i>	<i>T</i>	<i>S</i>	<i>FD</i>	<i>ER</i>	<i>RP</i>	<i>OS</i>
Mean Value	1.009	59.32	0.355	0.389	0.443	2.614	0.022
Maximum Value	2.241	430	0.802	0.967	5.926	18.02	0.238
Minimum Value	0.481	1	0.085	0.052	0.005	0.649	0.0004
Standard Deviation	0.093	74.167	0.065	0.118	0.477	1.541	0.024
Observations	3990	3990	3990	3990	3990	3990	3990

5. Empirical Results and Discussion

5.1. Analysis of Single Driving Factor

Technological innovation has become an important force driving economic growth worldwide. At present, the large-scale dividend released by the technological revolution and the great strategic transformation from extensive development to green development in China in the current era forms a historical intersection, which is both an opportunity and a challenge for China's cities to transform the model of economic growth and reshape the competitiveness of urban green development. In 2012, the report of the 18th National Congress of the Communist Party of China clearly put forward an innovation-driven development strategy, in particular pointing out the significance of scientific and technological innovation for economic and social development. Relying on technological innovation to drive urban green economic growth is the essence of the high-quality development of Chinese cities in the new era.

Based on the above analysis, this paper first uses the panel Granger causality model to test the relationship between technological innovation and urban green economic growth. Initially, Fisher's test was used for the unit root test and the specific results are shown in Table 3.

Table 3. Unit root test of T and Y .

Variable	P	Z	L^*	Pm	Unit Root	Result
Y	1826.0479 ***	−27.2645 ***	−29.4584 ***	39.6716 ***	No	Stationary
T	1805.4537 ***	−27.7658 ***	−29.6263 ***	39.0397 ***	No	Stationary

Note: *** indicates the significance level of 1%; P , Z , L^* and Pm indicate the Fisher unit root test statistics obtained after the inverse chi-squared transformation, inverse normal transformation, inverse logit transformation, and modified inverse chi-squared transformation, respectively.

Table 3 shows that Y and T are stationary sequences, and Granger causality analysis can be directly performed. The specific results are shown in Table 4.

Table 4. Granger causality test results of T and Y .

H_0		Lag Period 1	Lag Period 2	Lag Period 3
T is not the Granger cause of Y	w	2.8215	5.6325	5.5749
	z	0.2468	29.6221	17.1447
	p	0.1327	0.0000	0.0000

The Granger causality test shows that the coefficient is not significant in the short run, indicating that technological innovation is not the short-term Granger cause of urban green economic growth. In the long run, the coefficient is not zero, which indicates that when the fluctuation of technological innovation deviates from the long-term equilibrium, the system can pull technological innovation from the non-equilibrium state back to the equilibrium state; that is, there is a long-term stable equilibrium relationship between technological innovation and urban green economic growth, and technological innovation is the long-term Granger cause of urban green economic growth. This conclusion shows that the driving effect of technology innovation on green economic growth is not significant in the short term, owing to the low investment in independent R&D, the low efficiency of technology transformation and the obstacles in the introduction of technology. However, in the long run, as technology innovation ability has been significantly improved, technological innovation is an important driving force of urban green economic growth in China.

In modern economic growth theory, institutional factors are an important means of influencing economic growth. The government can promote the quality of economic growth through reasonable institutional arrangements. In the face of institutional obstacles in the process of urban green economic growth, the only way to solve them is to strengthen institutional innovation. According to the nature of green economic growth, we propose a

series of innovative institutional supplies that can fundamentally coordinate the interests of different subjects in green economic growth and thus establish effective constraints on and incentives for economic activities. Therefore, reasonable and effective institutional innovation is the only way to achieve urban green economic growth.

Similar to Section 5.1, this paper uses the panel Granger causality model to test the relationship between institutional innovation and urban green economic growth. Similarly, Fisher's test is used to test institutional innovation and urban green economic growth. The specific results are shown in Table 5.

Table 5. Unit root test of *S/FD/ER/RP/OS* and *Y*.

Variable	<i>P</i>	<i>Z</i>	<i>L*</i>	<i>Pm</i>	Unit Root	Result
<i>Y</i>	1826.0479 ***	−27.2645 ***	−29.4584 ***	39.6716 ***	No	Stationary
<i>S</i>	1753.5605 ***	−27.5102 ***	−28.7141 ***	37.4493 ***	No	Stationary
<i>FD</i>	2055.8122 ***	−32.2670 ***	−34.2978 ***	46.7155 ***	No	Stationary
<i>ER</i>	1537.1926 ***	−23.0821 ***	−23.9355 ***	30.2901 ***	No	Stationary
<i>RP</i>	1499.2556 ***	−21.8043 ***	−23.0876 ***	29.4691 ***	No	Stationary
<i>OS</i>	1832.8138 ***	−28.678 ***	−30.2864 ***	39.8970 ***	No	Stationary

Note: *** indicates the significance level of 1%; *P*, *Z*, *L** and *Pm* indicate the Fisher unit root test statistics obtained after the inverse chi-squared transformation, inverse normal transformation, inverse logit transformation, and modified inverse chi-squared transformation, respectively.

Table 5 shows that *Y* and *S/FD/ER/RP/OS* are stationary sequences, and Granger causality analysis can be directly performed. The specific results are shown in Table 6.

Table 6. Granger causality test results of *S/FD/ER/RP/OS* and *Y*.

<i>H</i> ₀		Lag Period 1	Lag Period 2	Lag Period 3
<i>S</i> is not the Granger cause of <i>Y</i>	<i>w</i>	2.0582	3.4272	12.5828
	<i>Z</i>	12.2040	11.6384	63.8057
	<i>P</i>	0.0000	0.0000	0.0000
<i>FD</i> is not the Granger cause of <i>Y</i>	<i>w</i>	4.0950	3.4524	11.3493
	<i>Z</i>	0.2221	3.3981	10.3554
	<i>P</i>	0.8243	0.0007	0.0000
<i>ER</i> is not the Granger cause of <i>Y</i>	<i>w</i>	4.9399	3.8932	1.6737
	<i>Z</i>	−0.1078	5.3043	3.5604
	<i>P</i>	0.9142	0.0000	0.0004
<i>RP</i> is not the Granger cause of <i>Y</i>	<i>w</i>	2.0198	4.3470	5.1362
	<i>Z</i>	6.2964	7.2671	14.2232
	<i>P</i>	0.0000	0.0000	0.0000
<i>OS</i> is not the Granger cause of <i>Y</i>	<i>w</i>	4.2090	1.4582	9.5896
	<i>Z</i>	6.6700	1.8632	7.4855
	<i>P</i>	0.0000	0.0624	0.0000

The Granger causality test shows that, whether it is short-term or long-term when the fluctuation of institutional innovation deviates from the equilibrium, the system has the relevant mechanism to automatically correct the degree of deviation, which can pull the institutional innovation from the nonequilibrium state back to the equilibrium state; that is, there is a stable equilibrium relationship between institutional innovation and green economic growth. At present, China's urban green economic growth still has much room for improvement, so it is necessary to further constrain and incentivise institutional innovation.

Next, this paper further analyses the impact of different types of institutional innovation on green economic growth. First, the innovation of fiscal decentralisation systems is not the short-term Granger cause of urban green economic growth but rather the long-term Granger cause of urban green economic growth. This conclusion shows that the driving effect of China's fiscal decentralisation system on green economic growth is not significant in the short term, which may be because other supervision systems compatible with the fiscal decentralisation system are not perfect in the short term, and local governments can

reduce tax rates or environmental regulatory standards to attract factor inflow and cause environmental pollution. However, in the long run, with the gradual improvement of the system, the fiscal decentralisation system enables local governments to use fiscal funds more flexibly to promote urban green economic growth. Second, the innovation of the environmental regulation is not the short-term Granger cause of urban green economic growth but the long-term Granger cause of urban green economic growth. This conclusion shows that the driving effect of China's environmental regulation system on green economic growth is not significant in the short term, which preliminarily confirms the rationality of the Porter hypothesis. That is, in the short run, due to the adoption of more stringent environmental regulation, the costs of energy conservation and emission reduction may increase, indicating that the causal relationship between environmental regulation and green economic growth is not significant or even has a negative impact. However, in the long run, with the improvement of technological innovation ability, environmental regulation can produce an "Innovation Compensation" effect, which is conducive to the promotion of urban green total factor productivity. Third, there is always a stable equilibrium relationship between the innovation of the resource pricing system and green economic growth. This conclusion shows that allowing the market to play a decisive role in resource allocation can effectively improve resource utilisation efficiency and promote urban green economic growth. Finally, regarding the opening-up system, the innovation of the opening-up system is not the Granger cause of green economic growth in the medium term, but rather the short-term and long-term Granger cause of urban green economic growth. This may be because, in the early stage of opening-up, the large-scale entry of foreign capital led to the continuous expansion of the total social demand, which effectively promoted economic development. To a certain extent, the economic benefits "covered" the environmental costs, which had a positive role in promoting green economic growth; however, with the continuous acceleration of industrialisation, the resource and environmental constraints are increasingly tight, and economic growth is slowing down, so the causal relationship between the opening-up system and the green economic growth is not very significant. In the long run, the quality of the level of opening-up and the quality of local economic development are gradually improved, suggesting another coordination relationship between the opening-up system and urban green economic growth.

5.2. Analysis of Multiple Driving Factors

In the first two sections, this paper conducts an empirical test on the correlation and causality between technological innovation and institutional innovation and urban green economic growth, but the correlation analysis and causality analysis are only on a single dynamic factor without considering other factors; thus, the results may be one-sided. To explore the driving effects of various factors more comprehensively on urban green economic growth in China to provide a reasonable empirical basis for related innovation policy measures and to promote technological progress, this paper puts technological innovation, institutional innovation and urban green economic growth into a unified research framework and empirically studies the dynamic relationship between them.

Before the SYS-GMM estimation, we should first use the VIF to test whether there are multiple collinearity problems among the explanatory variables. The results of the VIF tests show that the largest variance expansion factor is far less than 10, so there is no multiple collinearity problem among the explanatory variables. Table 7 reports the estimation results of the SYS-GMM.

Table 7. The Estimation Results of SYS-GMM.

	Equations (3)–(10)	Equations (3)–(11)
$Y(-1)$	0.249 *** (2.92)	0.241 *** (2.73)
S	0.308 *** (5.30)	
T	0.221 *** (4.23)	0.196 ** (2.02)
FD		0.0981 *** (2.99)
ER		0.021 ** (1.98)
RP		0.123 *** (3.87)
OS		0.029 (1.05)
$OS \times T$		0.016 *** (3.14)
$ER \times T$		0.293 * (1.69)
Sargan Test	0.355	0.577
AR(1)	−2.847 0.000	−3.026 0.002
AR(2)	1.049 0.293	0.981 0.327
Wald-test-P	0.000	0.000

Note: ① ***, **, and * indicate significance levels of 1%, 5% and 10%, respectively; the data in brackets are Z-statistic values, and ② The Sargan test column lists the test value and p -value of over-recognition. AR(1) and AR(2) represent the Arellano-Bond autocorrelation test results of first-order and second-order residual sequences, respectively.

First, the p -values of the Sargan test results estimated by GMM are all greater than 0.05, meaning that the original hypothesis of “All instrumental variables are valid” can be accepted at the significance level of 5%. The results of the Arellano-Bond autocorrelation show that $AR(1) < 0.05$ and $AR(2) > 0.05$, which indicates that the residuals only have first-order sequence correlation but no second-order sequence correlation; that is, the original hypothesis of “No autocorrelation of disturbance term” can be accepted. The Wald test shows that the overall model is highly significant, meaning that the estimation of SYS-GMM is valid.

Second, from the estimation results of each variable coefficient, the first-order lag term of GTFP has a significant positive effect on the current value, which shows that the change in GTFP is a dynamic process; that is, green economic growth is a continuous cycle accumulation process. Both institutional innovation and technological innovation can significantly promote urban green economic growth, and of the two, institutional innovation has a stronger positive impact on urban green economic growth. Furthermore, the coefficient sign of the fiscal decentralisation system is significantly positive. In the 11th Five-Year Plan, the energy conservation and emission reduction targets are linked with the performance evaluation of government officials for the first time, which gradually breaks the “ONLY GDP” of official evaluations. This has had an important impact on the transformation of China’s economic development model. After the 18th National Congress of the Communist Party of China, the Party Central Committee takes green as the background of economic development, and the fiscal decentralisation system with Chinese characteristics further enables local government to have greater financial and

administrative freedom, which has a significant positive effect on promoting urban green economic growth. The coefficient sign of environmental regulation systems is significantly positive, indicating that environmental regulation can promote the growth of the urban green economy, and the interaction coefficient of environmental regulation systems and technological innovation is also significantly positive, which further verifies that the effect of environmental regulation on green total factor productivity in China has crossed the “Porter Inflection Point”; that is, environmental regulations play a stable and significantly positive role in green economic growth. The coefficient sign of the resource pricing system is also significantly positive, which shows that letting the market play a decisive role in resource allocation can significantly improve resource utilisation efficiency and promote urban green economic growth. The coefficient sign of the opening-up system is positive, but not significant, while the coefficient of the interaction between opening-up and technological innovation is significantly positive, which indicates that the opening-up system at present can indirectly promote urban green economic growth through the technology spillover effect, but the direct positive impact of opening-up on green economic growth is not significant.

5.3. Discussion

From the above empirical analysis, we can draw the following conclusions: both technological innovation and institutional innovation can significantly promote the growth of the urban green economy, but institutional innovation has a greater role in promoting the growth of the urban green economy than technological innovation. The relationship between institutional innovation and urban green economic growth is more stable. Most previous studies overemphasise the important role of technological innovation in green economic growth, which is a little one-sided [35,49]. It is hoped that this paper can arouse the government’s attention to institutional innovation. Further, the reasons why institutional innovation can contribute more to green economic growth are as follows:

First, institutional innovation can reduce transaction costs and improve the efficiency of resource allocation. When the transaction cost is greater than zero, different institutions will affect the efficiency of resource allocation, that is, continuous institutional innovation can make professional and cooperative large-scale production possible, to make more efficient use of various production factors, especially non-renewable resource factors.

Second, institutional innovation can stimulate green technology innovation. The modern patent system is considered to be an important reason for the emergence of the British Industrial Revolution. Clear property rights and efficient protection of property rights are the institutional guarantees for innovators to obtain innovative profits. With this guarantee, profit is not only the result of green technology innovation but also the driving force of green technology innovation.

Third, institutional innovation can restrict the behaviour of enterprises and the public. The implementation of the institutions depends on the national coercive force, which can restrict the non-green behaviour of enterprises and the public, to ensure that the green economic growth is more sustainable fundamentally.

6. Conclusions and Implications

6.1. Conclusions

Green economic growth is an economic growth mode with the goal of efficiency, harmony and sustainability under the constraints of ecological environment capacity and resource carrying capacity, which is the essence of China’s high-quality development. As a quality contribution to green economic growth, the key is to improve green total factor productivity, of which technological innovation and institutional innovation are the primary driving forces. Therefore, based on the panel data of 266 cities in China from 2004 to 2018, this paper first uses the Directional Distance Function and GML productivity index to measure the urban green total factor productivity considering the energy input and unexpected output to represent urban green economic growth and then studies the impact

of technological innovation and institutional innovation on urban green economic growth using the panel Granger causality test and the SYS-GMM dynamic panel model. The main conclusions are as follows.

First, China's urban green total factor productivity shows an increasing trend from 2004 to 2018, and the average green total factor productivity of cities is 1.0327, which shows that the actual total factor productivity growth of Chinese cities is 3.27% under the constraints of resources and environment, which is far lower than the actual average GDP growth rate of 9.14%. Furthermore, from the decomposition index of green total factor productivity, the decline of green total factor productivity mainly comes from the decline of green technology progress, and the improvement of green total factor productivity mainly comes from the rise of green technology efficiency.

Second, both technological innovation and institutional innovation can significantly promote the growth of the urban green economy, but institutional innovation has a greater role in promoting the growth of the urban green economy than technological innovation. In addition, the relationship between institutional innovation and green economic growth is more stable. Furthermore, the innovation of fiscal decentralisation system can promote urban green economic growth. The effect of the innovation of environmental regulation on green economic growth has crossed the "Porter Inflection Point". The innovation of the resource pricing system has initially highlighted the decisive role of the market in resource allocation. Although the innovation of opening-up system can promote green technology innovation, it has not yet played a role in promoting green economic growth.

6.2. Implications

To summarise, this study shows both the temporal trend analysis in terms of green total factor productivity and driving effect analysis in terms of technological innovation and institutional innovation. From these analyses, implications are obtained.

In the process of promoting urban green economic growth, we should promote institutional innovation and improve the top-level design. First, we should improve the protocols for official promotions using the green evaluation system. The establishment of an evaluation system based on green total factor productivity can form a significant positive incentive for the behaviour of officials at all levels. The second is to formulate appropriate environmental regulation intensity. The government should appropriately increase the intensity of regulation within a reasonable range to play a positive role in promoting technological innovation and green transformation. Third, we should deepen the market-oriented pricing system. The government should further relax the price controls of coal, electricity, oil, gas and other resource products, gradually establish a resource price formation mechanism that fully reflects the degree of resource scarcity and the relationship between market supply and demand so that factor prices can truly play the role of market "baton". Fourth, we should comprehensively deepen the opening-up system. The government should actively improve the investment environment and relax market access standards for investment. At the same time, the government should improve the ability of enterprises to digest, absorb and utilise imported advanced technologies and give full play to the "technology spillover" effect, demonstration effect and competition effect.

In addition, as to technological innovation, we should also strengthen technological innovation and lay a solid foundation for green transformation. First, we should increase investment in scientific and technological innovation. The government should increase the contributions of public finance and subsidies for scientific and technological achievements, in particular, providing financial subsidies and policy support to enterprises that participate in green technology innovation activities to lessen the pressure and difficulties faced by enterprises in green technology innovation. Second, it is necessary to clarify the main position of enterprise innovation. Given the role of market mechanisms, more enterprises with core green technologies can truly participate in green technology innovation and solve the current dilemma of disjointed scientific research. Third, we should promote the diffusion and transformation of technological innovation achievements. Through

industry-university-research arrangements, we can make effective docking relationships between various subjects so that scientific research can directly contribute to the green transformation of industry. Green transformation should also be closely coordinated with scientific research to promote the development of collaborations between higher education institutions, scientific research institutes and enterprises to advance innovation. We will carry out all-round cooperation in resource sharing and other aspects to effectively accelerate the application and the diffusion of green technological innovation achievements.

Although this study gives suggestions based on its analysis, it has limitations that inspire further research. Institutional innovation, the key variable in this study, is constructed based on four aspects: fiscal decentralisation system, environmental regulation, resource pricing system and opening-up system. The institutional innovation index constructed by this method is widely supported and used in the existing literature but still needs improvement. First, institutional innovation is reflected in all aspects of economic and social activities, but due to the availability of data at the city level, it can only be roughly reflected through the above four aspects. Second, the institutional innovation index depends heavily on official data, which, because government officials tend to present better numbers to further their political careers, may not reflect the real situation of institutional innovation in China. Future research based on more accurately designed data may reveal more interesting results.

Author Contributions: Conceptualization, J.H. and X.C.; methodology, Y.S.; software, J.H.; validation, J.H., X.C. and Y.S.; formal analysis, J.H.; investigation, X.C.; resources, J.H.; data curation, X.C.; writing—original draft preparation, J.H.; writing—review and editing, X.C.; visualization, X.C.; supervision, X.C.; project administration, J.H.; funding acquisition, J.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the Chinese National Funding of Social Sciences (Grant No. 18AJY010; Grant No.21CGL036).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting the reported results in the present study will be available on request from the corresponding author or the first author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The calculation steps of the environmental regulation intensity index are as follows:
(1) Define the relative level of the city's pollutant i emissions.

$$px_{ij} = \frac{p_{ij}}{P_{ij}} \quad (A1)$$

where p_{ij} is the emission per unit GDP of pollutant i of city j , P_{ij} is the emission per unit GDP of the whole; the larger the value of px_{ij} , the higher the emission level of pollutant i of city j .

(2) Overall average.

$$px_j = \frac{1}{n} (px_{1j} + px_{2j} + \cdots + px_{nj}) \quad (A2)$$

where px_j is the relative level of all pollutants in city j .

(3) Reverse processing to calculate the intensity index of environmental regulation.

$$ER = \frac{1}{px_j} \quad (A3)$$

px_j is a negative index. The larger the value of px_j , the lower the intensity of urban environmental regulation. Therefore, the ER intensity index can be obtained by reverse processing.

The specific steps of the improved CRITIC method are as follows:

(1) Standardize data.

For positive indicators:

$$X'_{irj} = [X_{irj} - \min(X_{irj})] / [\max(X_{irj}) - \min(X_{irj})] \quad (A4)$$

For negative indicators:

$$X'_{irj} = [\max(X_{irj}) - X_{irj}] / [\max(X_{irj}) - \min(X_{irj})] \quad (A5)$$

X_{irj} is the original data of the j -th index in the t -th year of city i , and then the standardized data are shifted one unit to the right.

(2) Calculate the standard deviation σ_j , correlation coefficient r_{jh} and entropy e_j .

(3) Calculate the weight of each index.

$$\lambda_j = \frac{(\sigma_j + e_j) \sum_{h=1}^n (1 - |r_{jh}|)}{\sum_{j=1}^n (\sigma_j + e_j) \sum_{h=1}^n (1 - |r_{jh}|)} \quad (A6)$$

(4) Calculate the comprehensive index of institutional innovation.

$$S = \sum_{j=1}^n \lambda_j X'_{irj} \quad (A7)$$

References

1. Yu, Y.; Yang, X.; Li, K. Effects of the terms and characteristics of cadres on environmental pollution: Evidence from 230 cities in China. *J. Environ. Manag.* **2018**, *232*, 179–187. [CrossRef] [PubMed]
2. Liu, H.; Zhou, G.; Wennersten, R.; Frostell, B. Analysis of sustainable urban development approaches in China. *Habitat Int.* **2014**, *41*, 24–32. [CrossRef]
3. State Intellectual Property Office of China. China Green Patent Statistics Report (2014–2017). Available online: <https://www.cnipa.gov.cn/> (accessed on 14 August 2021).
4. Zhang, C.; Guo, B.; Wang, J. The different impacts of home countries characteristics in FDI on Chinese spillover effects: Based on one-stage SFA. *Econ. Model.* **2014**, *38*, 572–580. [CrossRef]
5. Kuai, P.; Yang, S.; Tao, A.; Zhang, S.; Khan, Z.D. Environmental effects of Chinese-style fiscal decentralization and the sustainability implications. *J. Clean. Prod.* **2019**, *239*, 118089. [CrossRef]
6. Zefeng, M.; Gang, Z.; Xiaorui, X.; Yongmin, S.; Junjiao, H. The extension of the Porter hypothesis: Can the role of environmental regulation on economic development be affected by other dimensional regulations? *J. Clean. Prod.* **2018**, *203*, 933–942. [CrossRef]
7. Yan, D.; Kong, Y.; Ren, X.; Shi, Y.; Chiang, S. The determinants of urban sustainability in Chinese resource-based cities: A panel quantile regression approach. *Sci. Total Environ.* **2019**, *686*, 1210–1219. [CrossRef] [PubMed]
8. Zhao, S.X.; Chan, R.C.; Chan, N.Y.M. Spatial polarization and dynamic pathways of Foreign Direct Investment in China 1990–2009. *Geoforum* **2012**, *43*, 836–850. [CrossRef]
9. Liu, Z.; Xin, L. Has China's Belt and Road Initiative promoted its green total factor productivity?—Evidence from primary provinces along the route. *Energy Policy* **2019**, *129*, 360–369. [CrossRef]
10. Organization for Economic Cooperation and Development. *Green Growth: Overcoming the Crisis and Beyond*; OECD: Paris, France, 2011.
11. Li, X.X.; Pan, J.H. *China Green Development Index Annual Report*; Beijing Normal University Press: Beijing, China, 2010; p. 53. (In Chinese)
12. Ma, X.-L.; Bao, J.-G.; Ryan, C. Evaluating the Total Factor Productivity Growth of National Parks in China with Data Enveloped Analysis. *Asia Pac. J. Tour. Res.* **2009**, *14*, 385–402. [CrossRef]
13. Glass, A.; Kenjegaliev, K.; Paez-Farrell, J. Productivity growth decomposition using a spatial autoregressive frontier model. *Econ. Lett.* **2013**, *119*, 291–295. [CrossRef]
14. Shi, X.; Li, L. Green total factor productivity and its decomposition of Chinese manufacturing based on the MML index:2003–2015. *J. Clean. Prod.* **2019**, *222*, 998–1008. [CrossRef]
15. Helvoigt, T.L.; Adams, D.M. A stochastic frontier analysis of technical progress, efficiency change and productivity growth in the Pacific Northwest sawmill industry. *For. Policy Econ.* **2009**, *11*, 280–287. [CrossRef]

16. Zhang, Y.; Jin, P.; Feng, D. Does civil environmental protection force the growth of China's industrial green productivity? Evidence from the perspective of rent-seeking. *Ecol. Indic.* **2015**, *51*, 215–227. [CrossRef]
17. Li, B.; Dewan, H. Efficiency differences among China's resource-based cities and their determinants. *Resour. Policy* **2017**, *51*, 31–38. [CrossRef]
18. Chung, Y.; Färe, R.; Grosskopf, S. Productivity and Undesirable Outputs: A Directional Distance Function Approach. *J. Environ. Manag.* **1997**, *51*, 229–240. [CrossRef]
19. Chen, S.; Golley, J. 'Green' productivity growth in China's industrial economy. *Energy Econ.* **2014**, *44*, 89–98. [CrossRef]
20. Pang, R.-Z.; Deng, Z.-Q.; Hu, J.-L. Clean energy use and total-factor efficiencies: An international comparison. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1158–1171. [CrossRef]
21. Manello, A. Productivity growth, environmental regulation and win-win opportunities: The case of chemical industry in Italy and Germany. *Eur. J. Oper. Res.* **2017**, *262*, 733–743. [CrossRef]
22. Du, J.; Chen, Y.; Huang, Y. A Modified Malmquist-Luenberger Productivity Index: Assessing Environmental Productivity Performance in China. *Eur. J. Oper. Res.* **2018**, *269*, 171–187. [CrossRef]
23. Xian, Y.; Wang, K.; Shi, X.; Zhang, C.; Wei, Y.-M.; Huang, Z. Carbon emissions intensity reduction target for China's power industry: An efficiency and productivity perspective. *J. Clean. Prod.* **2018**, *197*, 1022–1034. [CrossRef]
24. Xia, F.; Xu, J. Green total factor productivity: A re-examination of quality of growth for provinces in China. *China Econ. Rev.* **2020**, *62*, 101454. [CrossRef]
25. Wang, Y.; Sun, X.; Guo, X. Environmental regulation and green productivity growth: Empirical evidence on the Porter Hypothesis from OECD industrial sectors. *Energy Policy* **2019**, *132*, 611–619. [CrossRef]
26. Gao, Y.; Zhang, M.; Zheng, J. Accounting and determinants analysis of China's provincial total factor productivity considering carbon emissions. *China Econ. Rev.* **2020**, *65*, 101576. [CrossRef]
27. Lan, S.; Tseng, M.-L.; Yang, C.; Huisingh, D. Trends in sustainable logistics in major cities in China. *Sci. Total Environ.* **2020**, *712*, 136381. [CrossRef] [PubMed]
28. World Bank. *Inclusive Green Growth: The Pathway to Sustainable Development*; World Bank: Washington, DC, USA, 2012.
29. Romer, P.M. Endogenous Technological Change. *J. Political Econ.* **1990**, *98*, S71–S102. [CrossRef]
30. Smulders, J.A.; Withagen, A.M. Green Growth: Lessons from Growth Theory World Bank Policy Research. Working Paper No. 6230. 2012. Available online: <https://ssrn.com/abstract=2162798> (accessed on 22 July 2021).
31. Liu, Y.; Li, Z.; Yin, X. Environmental regulation, technological innovation and energy consumption—A cross-region analysis in China. *J. Clean. Prod.* **2018**, *203*, 885–897. [CrossRef]
32. Zhang, J.; Chang, Y.; Zhang, L.; Li, D. Do technological innovations promote urban green development?—A spatial econometric analysis of 105 cities in China. *J. Clean. Prod.* **2018**, *182*, 395–403. [CrossRef]
33. Wang, H.; Wang, M. Effects of technological innovation on energy efficiency in China: Evidence from dynamic panel of 284 cities. *Sci. Total Environ.* **2019**, *709*, 136172. [CrossRef]
34. Liu, Y.; Zhu, J.; Li, E.Y.; Meng, Z.; Song, Y. Environmental regulation, green technological innovation, and eco-efficiency: The case of Yangtze river economic belt in China. *Technol. Forecast. Soc. Chang.* **2020**, *155*, 119993. [CrossRef]
35. Wang, H.; Cui, H.; Zhao, Q. Effect of green technology innovation on green total factor productivity in China: Evidence from spatial Durbin model analysis. *J. Clean. Prod.* **2020**, *288*, 125624. [CrossRef]
36. Govindan, K.; Rajendran, S.; Sarkis, J.; Murugesan, P. Multi criteria decision making approaches for green supplier evaluation and selection: A literature review. *J. Clean. Prod.* **2013**, *98*, 66–83. [CrossRef]
37. Davis, L.; North, D. Institutional Change and American Economic Growth: A First Step Towards a Theory of Institutional Innovation. *J. Econ. Hist.* **1970**, *30*, 131–149. [CrossRef]
38. Fang, H.; Feng, Q.Y.F.; Zhou, Y.R. International flow of production factors and quality of economic growth: The moderating effect based on social resource endowment. *World Econ. Res.* **2020**, *7*, 17–32. (In Chinese)
39. Wu, H.; Ren, S.; Yan, G.; Hao, Y. Does China's outward direct investment improve green total factor productivity in the "Belt and Road" countries? Evidence from dynamic threshold panel model analysis. *J. Environ. Manag.* **2020**, *275*, 111295. [CrossRef] [PubMed]
40. Albrizio, S.; Kozluk, T.; Zipperer, V. Environmental policies and productivity growth: Evidence across industries and firms. *J. Environ. Econ. Manag.* **2017**, *81*, 209–226. [CrossRef]
41. Li, B.; Wu, S. Effects of local and civil environmental regulation on green total factor productivity in China: A spatial Durbin econometric analysis. *J. Clean. Prod.* **2016**, *153*, 342–353. [CrossRef]
42. Song, Y.; Yang, T.; Li, Z.; Zhang, X.; Zhang, M. Research on the direct and indirect effects of environmental regulation on environmental pollution: Empirical evidence from 253 prefecture-level cities in China. *J. Clean. Prod.* **2020**, *269*, 122425. [CrossRef]
43. Zhang, D.; Vigne, S.A. How does innovation efficiency contribute to green productivity? A financial constraint perspective. *J. Clean. Prod.* **2020**, *280*, 124000. [CrossRef]
44. Song, X.; Zhou, Y.; Jia, W. How do Economic Openness and R&D Investment Affect Green Economic Growth?—Evidence from China. *Resour. Conserv. Recycl.* **2019**, *146*, 405–415. [CrossRef]
45. Lin, B.; Zhu, J. Fiscal spending and green economic growth: Evidence from China. *Energy Econ.* **2019**, *83*, 264–271. [CrossRef]
46. Sohag, K.; Taşkın, F.D.; Malik, M.N. Green economic growth, cleaner energy and militarization: Evidence from Turkey. *Resour. Policy* **2019**, *63*, 101407. [CrossRef]

47. Cheng, Z.; Li, X.; Wang, M. Resource curse and green economic growth. *Resour. Policy* **2021**, *74*, 102325. [[CrossRef](#)]
48. Reilly, J.M. Green growth and the efficient use of natural resources. *Energy Econ.* **2012**, *34*, S85–S93. [[CrossRef](#)]
49. Yuan, R.S.; Feng, C. Technological Innovation, Technological Gap and Regional Green Development in China. *Sci. Res.* **2016**, *34*, 1593–1600. (In Chinese)
50. Lin, Y.F. *System, Technology and Agricultural Development in China*; Green Publishing: Shanghai, China, 2008; p. 132. (In Chinese)
51. Aghion, P.; Howitt, P. *Endogenous Growth Theory*; MIT Press: Boston, MA, USA, 1998; p. 206.
52. Liu, G.; Wang, B.; Zhang, N. A coin has two sides: Which one is driving China's green TFP growth? *Econ. Syst.* **2016**, *40*, 481–498. [[CrossRef](#)]
53. Pastor, J.T.; Lovell, C.K. A global Malmquist productivity index. *Econ. Lett.* **2005**, *88*, 266–271. [[CrossRef](#)]
54. Granger, C.; Newbold, P. Spurious regressions in econometrics. *J. Econ.* **1974**, *2*, 111–120. [[CrossRef](#)]
55. Hartwig, J. Is health capital formation good for long-term economic growth?—Panel Granger-causality evidence for OECD countries. *J. Macroecon.* **2010**, *32*, 314–325. [[CrossRef](#)]
56. Arellano, M.; Bond, S. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *Rev. Econ. Stud.* **1991**, *58*, 277. [[CrossRef](#)]
57. Arellano, M.; Bover, O. Another look at the instrumental variable estimation of error-components models. *J. Econ.* **1995**, *68*, 29–51. [[CrossRef](#)]
58. Blundell, R.; Bond, S. Initial conditions and moment restrictions in dynamic panel data models. *J. Econ.* **1998**, *87*, 115–143. [[CrossRef](#)]
59. Chen, C.F. Green total factor productivity of China's industry and its influencing factors—An Empirical Study Based on ML productivity index and dynamic panel model. *Stat. Res.* **2016**, *33*, 53–62. (In Chinese)
60. Zhao, Z.Y.; Zhou, J.J.; Shen, N. An empirical study on the impact of financial development and regional innovation efficiency. *Sci. Stud.* **2016**, *34*, 1408–1416. (In Chinese)
61. Zhao, X.W. Environmental Regulation, Environmental Regulation Competition and Regional Industrial Economic Growth: An Empirical Study Based on Spatial Durbin Panel Model in Chinese. *Int. Trade* **2014**, *7*, 82–92. (In Chinese)
62. Jia, J.; Guo, Q.; Zhang, J. Fiscal decentralization and local expenditure policy in China. *China Econ. Rev.* **2014**, *28*, 107–122. [[CrossRef](#)]
63. Abdel-Basset, M.; Mohamed, R. A novel plithogenic TOPSIS- CRITIC model for sustainable supply chain risk management. *J. Clean. Prod.* **2019**, *247*, 119586. [[CrossRef](#)]

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.