

Research Article

Decomposition Analysis of Green Technology Innovation from Green Patents in China

Aiping Chen  and Huiying Chen 

College of Economics and Management, Shandong University of Science and Technology, Qingdao, Shandong 266590, China

Correspondence should be addressed to Aiping Chen; skd992057@sdust.edu.cn

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Green technology innovation is essential to promoting not only the construction of ecological civilization but also the fundamental means of achieving sustainable development. Taking research and development (R&D) investment, CO₂ emissions, and other related factors into account, this study constructed an extended logarithmic mean Divisia index (LMDI) decomposition model for the change in the number of green technology patent applications to quantify the contribution of each driving factor based on green patent applications data in China from 2000 to 2017. The results indicated that economic scale, R&D efficiency, R&D reaction, and green patent share play positive roles in promoting green patent applications in China, among which R&D efficiency is the most significant contributor. By contrast, carbon intensity plays a dampening role. The conclusions of this study could provide a theoretical foundation for China to formulate targeted green technology innovation management policies, promotion measures, and related R&D strategies.

1. Introduction

Climate change and CO₂ emissions mitigation have drawn global attention in recent years. Human beings have made considerable efforts to mitigate the impact of climate change and environmental degradation [1–3]. Documents such as the *United Nations Framework Agreement on Climate Change*, *Kyoto Protocol*, and *Paris Protocol* have emphasized the importance of CO₂ emissions reduction in the fight against climate change. Technological innovation is key to driving energy saving and CO₂ emission reduction, and this idea has gained a wide societal consensus [4–6]. The theme of World Intellectual Property Day 2020 was *Innovate for a Green Future*, which stressed on innovation being crucial to creating a greener tomorrow. Climate change has far-reaching effects for everyone, and innovation in green technology sectors will be vital to address this global challenge successfully [7, 8].

Growth in energy markets slowed in line with weaker economic growth in 2019. China was the exception, with its energy consumption accelerating in 2019. China was by far

the biggest driver of energy, accounting for more than three-quarters of net global growth in 2019 [9]. The nation was still the country with the world's highest CO₂ emissions, however, accounting for 28.8%. As the largest CO₂ emitter, the nation has more and more challenges in CO₂ emission reduction and sustainable development. As a result, China plays a crucial role in tackling climate change. China has made an ambitious aim to have CO₂ emissions peak before 2030 and achieve carbon neutrality before 2060.

Figure 1 shows the trend of China's annual gross domestic product (GDP) growth rate and CO₂ emissions from 2000 to 2019. China's GDP growth rate increased annually until 2007; however, it dramatically slowed in 2008 because of the worldwide financial crisis. After 2008, the nation's GDP growth rate gradually decreased. The bars illustrate CO₂ emissions from 2000 to 2019 in China. Notably, CO₂ emissions have continued to grow despite the reduced economic growth rate since 2008. As China is facing restraints on its resources and the environment, how to balance the relationship between environmental protection and economic development is especially important [5, 10–12].

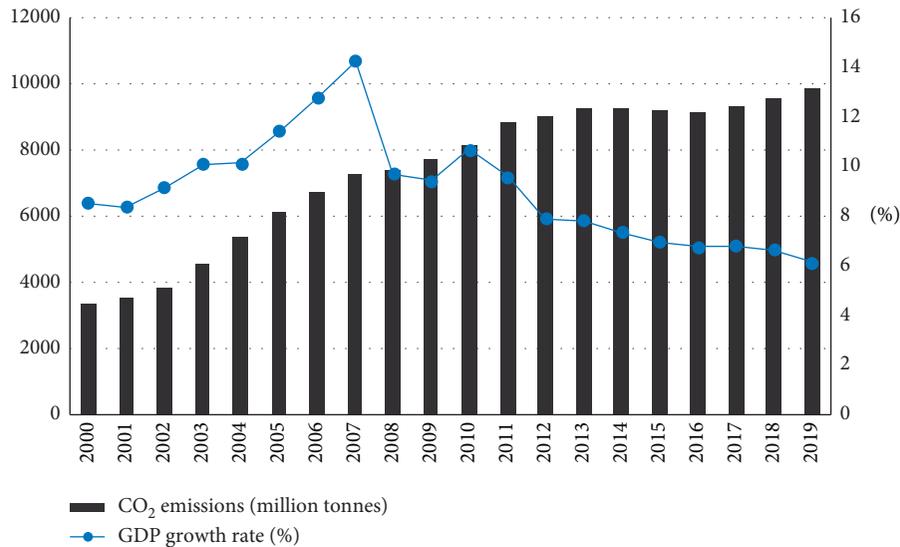


FIGURE 1: Trends of GDP growth rate and CO₂ emissions in China in 2000–2019. Data source: China Statistical Yearbook (2020) and BP Statistical Review of World Energy (2020).

Green technology innovation helps balance the relationship between environmental protection and economic development; however, it is also key to building a sustainable society, which is becoming more important around the globe, especially in China [7, 13–15].

In fact, it was a weak sustainable development model until the 12th Five-Year-Plan period in China was released, which, for the first time, focused on the concept of strong sustainability. Green growth was popular afterwards including the advocacy of green innovation [16]. China has introduced the new development concepts for the 13th Five-Year Plan, which has placed “innovative” and “green” development in an important position. The focus of innovative development is to address the issue of growth drivers, whereas the focus of green development is to address the issue of harmony between humankind and nature. China has transformed its economy from a high-speed growth stage to a high-quality development stage, and the organic combination of innovation-driven and green development is a critical way to achieve high-quality development. As a crucial method in promoting the construction of ecological civilization and green development, green technology innovation has both technology spillovers and environmental externalities in China. Under the principles of innovative and green development, exploring the driving factors of green technology innovation is of marked significance to promote the development of green technology and the formulation of related policies.

The purpose of this paper is to explore the determinants of green patent applications in China from 2000 to 2017 through the logarithmic mean Divisia index (LMDI) analysis framework. Our study not only examines the influencing factors of green patent applications in China but also evaluates the effects of CO₂ emissions and the efficiency of R&D expenditure.

The remainder of this paper is arranged as follows. Section 2 reviews the relevant and informative literature.

Section 3 explains the LMDI decomposition method and data source. Section 4 covers the empirical results from the decomposition analysis of green technology patent applications in China. Finally, Section 5 comes to conclusions and proposes policy implications.

2. Literature Review

Braun first proposed the concept of green technology [17]. With the increasingly severe problems of global climate change and environmental degradation, more scholars have begun to pay attention to green technology innovation. These studies have focused on the definition and mode of green technology innovation and its motivation, efficiency, and influencing factors. The research scope of these studies has involved the country level, industrial level, or firm level [4, 18–23]. In terms of factors affecting green technology innovation, numerous scholars have studied the impact of environmental regulations on green technology innovation and drawn valuable conclusions [24, 25]. Most conclusions are consistent with the Porter hypothesis viewpoint [26], which suggests that the environmental regulation has a positive role in promoting green technology innovation [27–30]. Some scholars’ conclusions, however, are inconsistent with the Porter hypothesis [31, 32]. Their studies found that (1) environmental regulations will have an inhibitory effect on enterprises’ competitiveness, and (2) such regulations will have only a tenuous promotional effect on green technology innovation. In addition to the influence of environmental regulation factors, some scholars consider the impact of alternative factors—economic development level, R&D investment, CO₂ emissions, and government subsidies—on green technology innovation [3, 33–37]. However, the relationship between CO₂ emissions and R&D investment in green technologies has rarely been discussed.

The measurement of green technology innovation includes three primary indicators: the amount of R&D,

number of green patents, and green total-factor productivity; these represent the input, output, and performance of green technology innovation, respectively. Since Lanjouw and Mody [29] first introduced patent data into the study of green technology innovation, research in this field has reached constructive results [33, 38–40]. To explore the effect of green technologies, patent data has been used [41–44]. However, because of incomplete green patent statistics, studies on technological innovation based on China's green patents are still limited [3, 18, 33, 44, 45]. Fujii used patent data combined with the LMDI method to study the determinants of green technology inventions in China from the 9th Five-Year Plan to the 12th Five-Year Plan and focused on analyzing the differences in green technology development priorities during each five-year plan [44]. Chen and Lin made a decomposition analysis of patenting in renewable energy technologies from an extended LMDI approach based on three Chinese five-year-plan periods [46].

From the perspective of research methods, decomposition analysis has been widely utilized to quantify the variations in energy consumption and CO₂ emissions. There are primarily two categories of the decomposition approach: structure decomposition analysis (SDA) and index decomposition analysis (IDA). SDA is widely used in revealing the role of structure change [47]. IDA can be implemented using either the Laspeyres index or the Divisia index. Ang proposed the logarithmic mean Divisia index (LMDI) method [47]. In contrast, the LMDI method does not produce unexplained residual terms, handles zero values, and is easy to conduct for comparative studies [49]. Because of its merits, the LMDI method is widely applied in energy and environmental science to address issues such as climate change and energy security [10, 48, 50–52]. In general, the LMDI method is rarely used to decompose green patent counts. Based on patent data, researchers have applied the extended LMDI method to study green chemical [43], biological [35], food waste management [53], fishery [54], and artificial intelligence technologies [21]. Cho and Sohn not only used LMDI decomposition to evaluate the impact of changes in CO₂ emissions on green R&D investment and related patents but also compared the primary factors driving green patent applications in France, Germany, Italy, and the United Kingdom [42]. Fujii and Managi applied the LMDI method to study China's sustainable green technology; the study considered the decomposed factors, including the priority of specific green technology, share of green patents, R&D share, and GDP scale [44].

Although countless efforts have been made to explore the factors influencing green technology innovation, this study highlights a few gaps in the literature. First, the majority of previous studies have focused on environmental regulations; however, little attention has been paid to the CO₂ emissions and R&D activities factors. Second, most of the previous literature has centered on the presentation of econometric results but has rarely applied the patent decomposition method. Most importantly, much of the previous research has investigated green technologies in developed countries but rarely discussed them in developing countries.

To fill in the previously mentioned gaps, this paper identifies the central drivers behind China's green technology innovation and focuses on CO₂ emissions and R&D activities based on an extended LMDI decomposition analysis. Moreover, this paper evaluates China's underlying policies and implemented measures and discusses the role of R&D activities in green technology innovation.

Our study's contributions are as follows. First, we extend the LMDI by introducing CO₂ emissions and R&D activities into green technology patent decomposition study. Second, we discuss the decomposition results through two ways: time-series decomposition analysis and period-wise decomposition analysis, which may provide a lot of new information for policy makers. In this regard, this study can provide insights for formulating different policies.

3. Methodology and Data

The LMDI method can be used for either multiplicative or additive decompositions [47]. Although the two decomposition forms' results are different, the same conclusions can be drawn in regard to analyzing influencing factors. In this study, we used the additive LMDI method because it is easy to examine the number of green patent application changes influenced by each factor.

Through expanding the Kaya identity [55] and highlighting the influence of carbon emissions and R&D activities on green technology innovation, this paper builds an additive LMDI decomposition model to decompose the influencing determinants of green technology innovation output change in China. We use this method to study the driving factors of green technology innovation because it can wholly decompose the changes in green technology innovation into five factors—economic scale, carbon emission intensity, R&D response, R&D efficiency, and green patent shares—and can effectively avoid problems, such as endogeneity, which may arise when using regression analysis.

3.1. Model Construction. As opposed to previous studies, this paper takes carbon emission intensity, R&D response, and R&D efficiency as essential factors of the extended LMDI decomposition framework. There are no definite study conclusions about the time lag between environmental changes and R&D investment changes. To achieve the goals of the *Kyoto Protocol* or *Paris Protocol*, countries often determine the amount of R&D investment in the current year based on the previous year's CO₂ emission level. Some studies consider a one-year time lag between R&D investment and CO₂ emissions [42]. Besides considering the impact of GDP on R&D investment, this study includes the one-year time lag of GDP and CO₂ emissions in the decomposition model as driving factors of green technology innovation.

In related studies, the indicators for measuring green technology innovation output included chiefly new product sales revenue and green patent quantity; however, new product sales revenue is more suitable for the enterprise level, and the impact of factors such as marketing strategies

on sales revenue cannot be excluded. Therefore, this study uses the number of green patent applications as a measurement of green technology innovation. Patents are also closely related to R&D activities. Some studies have shown that a time lag of approximately one to two years exists between R&D investment and patent applications [55–57], while other studies have found that a strong correlation lies between patent applications and R&D investments with a very little lag. In particular, a study by Brunnermeier and Cohen has shown there is no time difference between R&D investment and environmental patent applications [48]; therefore, this study does not consider the time lag between them.

We applied a patent decomposition analysis approach to identify the driving factors associated with green patent applications. Based on the existing literature [37, 46] and combined with the actual situation of green development in China, we used five indicators to decompose green patents. The detailed process of the patent decomposition method is expressed as follows:

$$P_{\text{GREEN}t} = \text{GDP}_{(t-1)} \times \frac{\text{CO}_2(t-1)}{\text{GDP}_{(t-1)}} \times \frac{\text{R\&D}_t}{\text{CO}_2(t-1)} \times \frac{P_{\text{TOTAL}t}}{\text{R\&D}_t} \times \frac{P_{\text{GREEN}t}}{P_{\text{TOTAL}t}}, \quad (1)$$

where P_{GREEN} is the number of green patent applications; GDP denotes the gross domestic product; CO_2 is carbon emissions; R&D is a research and development investment; P_{TOTAL} is the total number of patent applications.

Subsequently, (1) is further simplified as follows:

$$P_{\text{GREEN}t} = G_{(t-1)} \times I_{(t-1)} \times R_t \times E_t \times S_t, \quad (2)$$

where G is the gross domestic product, which indicates the economic scale; I is the intensity of carbon emissions, which indicates CO_2 emissions per unit of GDP; R is the R&D reaction, which shows the response of R&D expenditures with the changes in CO_2 emissions; E is R&D efficiency, which indicates the green patent output per unit of R&D input; S is defined as the total number of green patent applications divided by the total number of patent applications, which yields the share of green patent applications. This indicator shows the direction of technological innovation. The higher the proportion, the more apparent the green tendency of technological innovation. Equation (2) explains that the number of green patent applications is affected by economic scale, CO_2 emission intensity, R&D reaction, R&D efficiency, and green patent share.

According to the LMDI additive decomposition, the changes in the number of green patent applications from the base year B to a target year T can be represented as follows:

$$\Delta P_{\text{GREEN}} = P_{\text{GREEN}}^T - P_{\text{GREEN}}^B = \Delta P_{\text{gdp}} + \Delta P_{\text{int}} + \Delta P_{\text{rea}} + \Delta P_{\text{eff}} + \Delta P_{\text{str}}. \quad (3)$$

Equation (3) denotes that the change in the number of green patent applications can be decomposed into economic

scale effect (ΔP_{gdp}), carbon emission intensity effect (ΔP_{int}), R&D reaction effect (ΔP_{rea}), R&D efficiency effect (ΔP_{eff}), and green patent share effect (ΔP_{str}), which, respectively, indicate the contribution value of each factor to the change of green patent applications. If the decomposition effect is a positive value, then, it will have a favorable driving impact on the green technology innovation output. If it is a negative value, then, it exerts a negative impact on green technology innovation output.

The LMDI decomposition method includes an additive version and a multiplicative version that produces similar results. In this paper, we applied the additive decomposition method for decomposing changes in the number of green patent applications. The calculation process is shown as follows:

$$\begin{aligned} \Delta P_{\text{gdp}} &= \omega_i \ln \left(\frac{G^{T-1}}{G^{B-1}} \right), \\ \Delta P_{\text{int}} &= \omega_i \ln \left(\frac{I^{T-1}}{I^{B-1}} \right), \\ \Delta P_{\text{rea}} &= \omega_i \ln \left(\frac{R^T}{R^B} \right), \\ \Delta P_{\text{eff}} &= \omega_i \ln \left(\frac{E^T}{E^B} \right), \\ \Delta P_{\text{str}} &= \omega_i \ln \left(\frac{S^T}{S^B} \right), \end{aligned} \quad (4)$$

where ω_i is the estimated weight, which is the conventional processing method of the additive LMDI approach, and this weight is defined as

$$\omega_i = \frac{P_{\text{GREEN}}^T - P_{\text{GREEN}}^B}{\ln P_{\text{GREEN}}^T - \ln P_{\text{GREEN}}^B}. \quad (5)$$

Following the decomposition approach, we also apply contribution rate analysis to further study the changing impact of drivers of the green patent over time. The contribution rate of each driving force is calculated by the following equations:

$$\begin{aligned} CR_{\text{gdp}} &= \frac{\Delta P_{\text{gdp}}}{\Delta P_{\text{GREEN}}} \times 100\%, \\ CR_{\text{int}} &= \frac{\Delta P_{\text{int}}}{\Delta P_{\text{GREEN}}} \times 100\%, \\ CR_{\text{rea}} &= \frac{\Delta P_{\text{rea}}}{\Delta P_{\text{GREEN}}} \times 100\%, \\ CR_{\text{eff}} &= \frac{\Delta P_{\text{eff}}}{\Delta P_{\text{GREEN}}} \times 100\%, \\ CR_{\text{str}} &= \frac{\Delta P_{\text{str}}}{\Delta P_{\text{GREEN}}} \times 100\%. \end{aligned} \quad (6)$$

3.2. Data. To apply the previously mentioned additive form of the LMDI method, we collected the necessary data related to GDP, CO₂ emissions, R&D expenditure, and patent data. Patent data usually include two types: patent applications and patent grants. Patent application data can reflect inventors' R&D activities and R&D strategies, and patent grant data represent the number of qualifying patent applications that are primarily used to examine the diffusion of technologies. Because patent grants are often granted long after the submission of the patent application, patent grant data can easily cause information distortion and are subject to human factors, such as differences between patent agencies in various countries, which causes uncertainty. Therefore, we use patent application data as the measurement of green technology innovation. Green patent application data come from the China National Intellectual Property Administration (CNIPA) patent search and analysis system. According to the international patent classification number corresponding to the World Intellectual Property Organization's (WIPO) list of green technologies, China's green patent invention and green utility model patents are counted to obtain the data on green patent applications from 2000 to 2017. China's R&D investment data and the total number of patent applications are taken from the China Statistical Yearbook on Science and Technology (2001–2018). To correspond to the green patent statistics, total patent data include the number of patent applications for green patent invention and green utility model patents. The R&D investment data include R&D expenditures of R&D institutions, universities, and large- and medium-sized industrial enterprises. The CO₂ emission data were compiled using the BP Statistical Review of World Energy (2001–2018), and the GDP data come from the China Statistical Yearbook (2001–2018). R&D expenditures and GDP were deflated based on the 2000 price to eliminate the influence of price fluctuations and make the yearly indicators comparable.

As previously mentioned, to reflect the time lag, however, the GDP and CO₂ emissions values used were from 1999 to 2016. The data used, including the R&D expenditure and related patent application data, referred to the interval from 2000 to 2017.

4. Results and Discussion

4.1. Trends of Green Patent Applications in China.

Figure 2 shows the number and share of green patent applications in China from 2000 to 2017. During this period, the number of green patent applications in China increased by 52.16 times. It has maintained an especially rapid growth since 2010. Economic growth has gradually slowed in China after the 2008 financial crisis, but the number of green patent applications maintains a relatively fast-growing trend. Although the proportion of green patents to total patent applications is not high, it has increased from 4.87% in 2000 to 8.31% in 2017, indicating clear growth potential.

4.2. LMDI Analysis. In general, there are two types of decomposition analysis mode: the period-wise manner and the

time-series manner. The period-wise manner compares indices between the first and last years of a given period without considering the details during different periods. Time-series analysis can compare the indices on an annual basis. To better analyze the influencing factors of green technology innovations, we employed the period-wise and time-series forms to study the driving factors that can change the number of green patent applications in China.

4.2.1. Period-Wise Decomposition Analysis. We analyzed the five determinants of green patent applications from 2000 to 2017. Following the five-year plan in China, we subdivided the study period into four intervals of five years and one period of one year, 2016–2017. The determinants of green patent applications and their relative contribution value and contribution rate are presented in Table 1 and Figure 3.

As shown in Table 1, the number of green patent applications in China dramatically increased by 238,473 from 2000 to 2017, especially in 2011–2015 (12th Five-Year Plan) and 2016–2017. Overall, economic activity, R&D reaction, R&D efficiency, and green patent share played promoting roles in the increased number of green patent applications from 2000 to 2017. Among the positive effects, the R&D efficiency factor is the dominant factor, and economic activity is the second most important factor affecting green patent applications. By contrast, carbon emission intensity played a negative role in the increased number of green patent applications.

Differences exist in various intervals. We applied the contribution rate to investigate each factor's contribution degree. As shown in Figure 3, the contribution rate fluctuated during the study period of 2000–2017. During 2000–2005, the contribution rate of the R&D reaction effect was negative, indicating an inhibiting effect on the increased number of green patent applications in comparison with other positive drivers. By contrast, the carbon emission intensity effect was positive in this period. Nevertheless, from 2006 to 2017, the carbon emission intensity effect played a negative role, and the R&D reaction effect played a promoting role in the increased number of green patent applications. Besides the 2016–2017 period, the green patent share had a significant contribution to the change in green patent applications, accounting for 61.44%.

4.2.2. Time-Series Decomposition Analysis. Compared with the period-wise decomposition, using the time-series mode to decompose the change factors of green technology patent applications year by year can provide more detailed information. Table 2 shows the time-series decomposition results of the changes in the number of green patent applications in 2000–2017.

The results show that all influencing factors contributed differently to the change in green patent applications in various years and grew involved in largely disparate influence with respect to time series. Based on the results in Table 2, further analysis of the change in influence factors based on China's actual situation was conducted as follows.

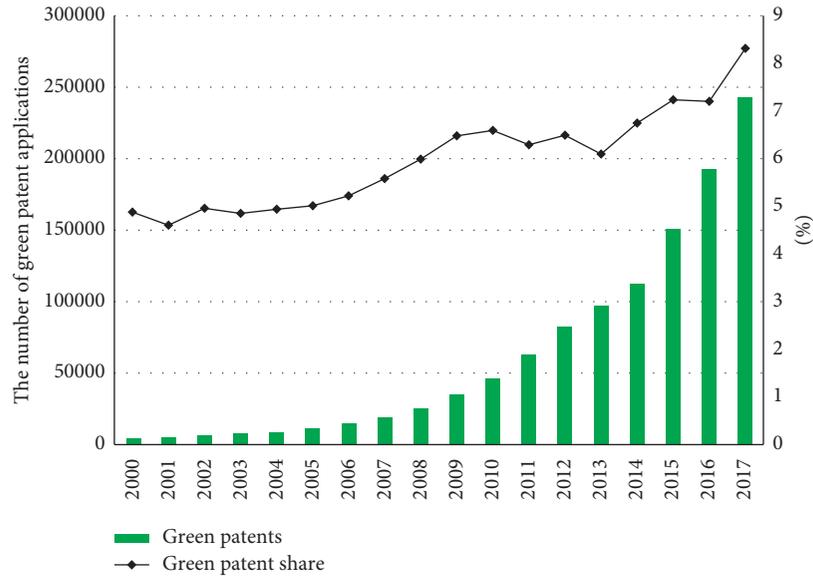


FIGURE 2: Trends of green technology patent application in China in 2000–2017. Data source: China and Global Patent Examination Inquiry from the CNIPA.

TABLE 1: Period-wise decomposition results of green patent applications in China in 2000–2017.

Effect	5-year intervals				Full period 2000–2017
	2000–2005	2006–2010	2011–2015	2016–2017	
ΔP_{gdp}	3320.52	11955.35	31372.04	14054.50	91669.06
ΔP_{int}	320.23	-5516.17	-18759.84	-15373.43	-30566.62
ΔP_{rea}	-121.15	4998.94	16346.27	15779.27	29674.96
ΔP_{eff}	3300.80	13544.22	45270.81	5080.47	115686.95
ΔP_{str}	205.59	6419.66	14046.73	31136.19	32008.65
ΔP_{GREEN}	7026	31402	88276	50677	238473

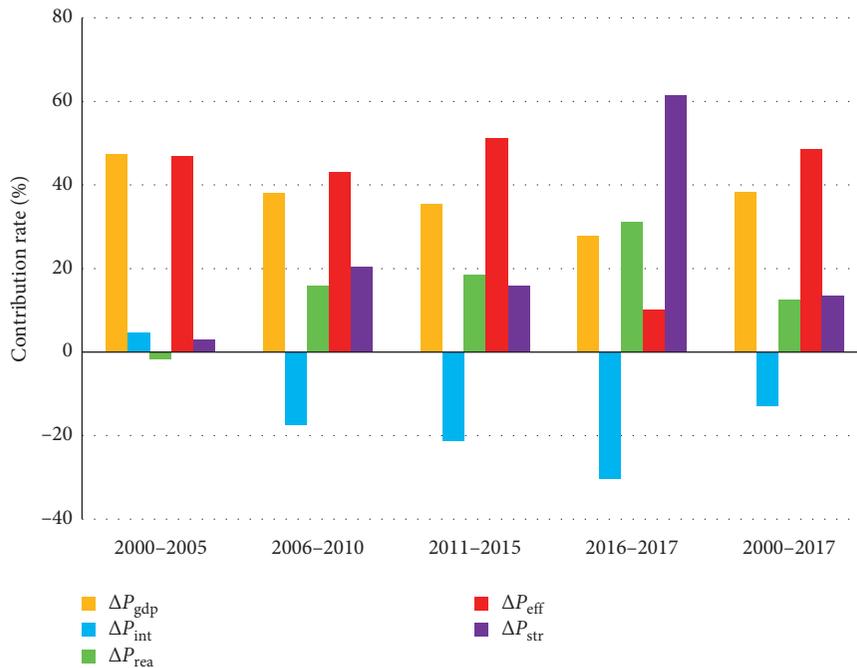


FIGURE 3: The contribution rate of each factor in the changes in the number of green patent applications in China during different periods.

TABLE 2: Year-by-year decomposition analysis results of green patent applications in China in 2000–2017.

Year	Economic activity		CO ₂ emission intensity		R&D reaction		R&D efficiency		Green patent share		Total
	ΔP_{gdp}	CR_{gdp} (%)	ΔP_{int}	CR_{int} (%)	ΔP_{rea}	CR_{rea} (%)	ΔP_{eff}	CR_{eff} (%)	ΔP_{str}	CR_{str} (%)	
2000-2001	391.4	85.1	-293.4	-63.8	284.5	61.9	351.4	76.4	-274.0	-59.6	460
2001-2002	458.6	30.5	-187.4	-12.5	229.8	15.3	582.5	38.7	420.6	28.0	1504
2002-2003	630.2	43.5	-0.7	-0.1	60.1	4.2	909.4	62.8	-151.1	-10.4	1448
2003-2004	797.1	103.4	581.2	75.4	-573.6	-74.4	-180.7	-23.4	146.9	19.1	771
2004-2005	972.8	34.2	674.9	23.7	-556.3	-19.6	1604.7	56.4	146.9	5.2	2843
2005-2006	1414.1	45.3	335.0	10.7	-183.1	-5.9	1029.3	32.9	529.7	17.0	3125
2006-2007	1982.0	51.4	-480.2	-12.5	699.3	18.1	539.0	14.0	1117.8	29.0	3858
2007-2008	2876.2	44.4	-1124.5	-17.3	253.7	3.9	2942.4	45.4	1536.2	23.7	6484
2008-2009	2748.5	28.1	-2187.2	-22.4	2105.9	21.5	4785.9	48.9	2329.9	23.8	9783
2009-2010	3613.7	32.0	-1852.2	-16.4	2291.0	20.3	6555.8	58.1	668.7	5.9	11277
2010-2011	5438.6	32.9	-2532.3	-15.3	1992.7	12.0	14176.3	85.6	-2517.3	-15.2	16558
2011-2012	6541.9	33.2	-832.2	-4.2	-228.8	-1.2	11941.1	60.6	2274.1	11.6	19696
2012-2013	6801.9	46.7	-4935.6	-33.9	4852.7	33.4	13410.4	92.2	-5578.3	-38.3	14551
2013-2014	7835.2	51.7	-5016.6	-33.1	4531.6	29.9	-2728.9	-18.0	10523.8	69.5	15145
2014-2015	9198.6	23.7	-9396.5	-24.2	8908.9	22.9	21062.4	54.2	9110.7	23.4	38884
2015-2016	11398.3	27.5	-12310.2	-29.7	11990.3	29.0	31135.7	75.2	-805.1	-1.9	41409
2016-2017	14054.5	27.7	-15373.4	-30.3	15779.3	31.1	5080.5	10.0	31136.2	61.4	50677

(1) *Economic Scale Effect.* Innovation and economic development complement each other. Innovation is an important driving force for economic growth. An increase in the level of economic development can provide a better environment and better conditions for technology innovation. Green technology innovation needs economic support. Generally speaking, the higher the level of economic development, the greater the amount of R&D investment, and the more the innovation output. China became the third-largest economy in the world in 2007 and the second largest in 2011, but growth has recently slowed. The decomposition results show that the economic scale has a significant positive role in promoting green technology innovation output, with an average contribution rate of 32.35%. As shown by the orange line in Figure 4, significant differences lie in the level of economic scale effect. In 2004-2005, the contribution rate of economic scale effect on green patent applications sharply decreased, which may be a byproduct of the 2003 SARS outbreak. Due to the impact of the 2008 financial crisis, China’s economic development has slowed; this has since reduced the impact of economic development on the number of China’s green technology patent applications.

(2) *Carbon Emission Intensity Effect.* Looking at Table 2, carbon emission intensity has a negative impact on green patent applications, except in the periods of 2003-2004, 2004-2005, and 2005-2006 (demonstrated by the blue line in Figure 4). In particular, the carbon emission intensity effect accounted for a reduction of approximately 33.9% in patent applications in 2012-2013. To date, China has become the country with the largest carbon emissions rate in the world. China must control its CO₂ emissions and reduce its carbon emissions intensity to achieve its low-carbon development goal.

(3) *R&D Reaction Effect.* R&D reaction refers to the response of R&D activities to changes in CO₂ emissions. With the

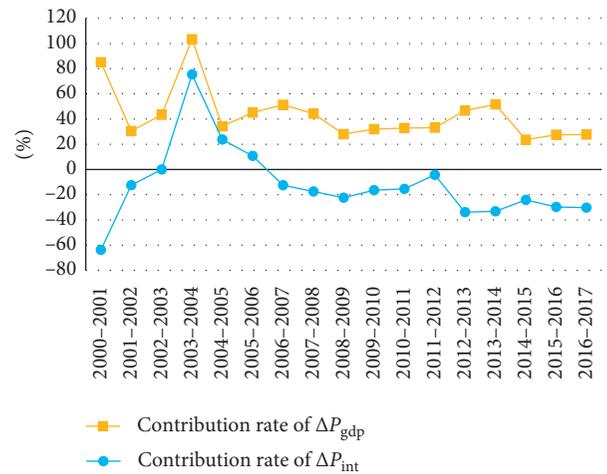


FIGURE 4: The trend of contribution rate of economic scale and carbon emissions intensity factors to China’s green patent applications increase from 2000 to 2017.

promulgation and implementation of China’s environmental regulation measures, CO₂ emissions control has become an important measure. To achieve energy conservation and emission reduction targets, investment funds for R&D continue to increase, thereby promoting green technology innovation output. Since the 12th Five-Year Plan (2011–2015) especially—with the country’s attention turned towards climate change, environmental issues, and determination of CO₂ emission targets—green technology innovation has been significantly affected. According to the decomposition results in Table 2, the R&D reaction effect is generally positive, except in the periods of 2003-2004, 2004-2005, 2005-2006, and 2011-2012.

(4) *R&D Efficiency Effect.* The decomposition results show that the R&D efficiency effect is the dominant driving force

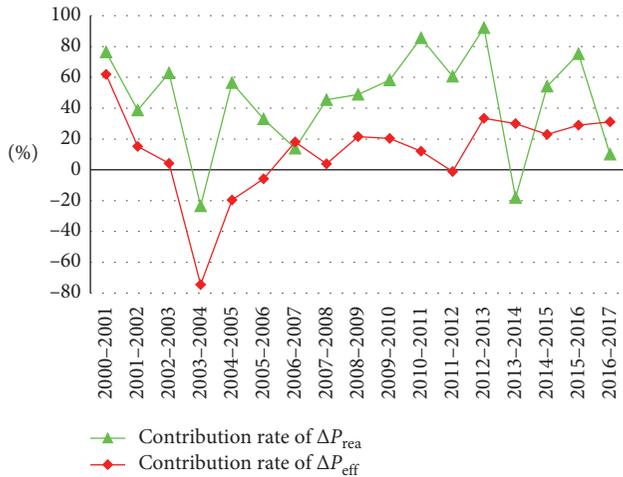


FIGURE 5: The trend of contribution rate of R&D activities factors to China's green technology innovation output from 2000 to 2017.

for the change in green patent applications, with a high contribution rate of 47.47%. Table 2 presents that the increase in R&D efficiency from 2000 to 2001 on green patents was only 351.4 and that the contribution value from 2015 to 2016 was as high as 31,135.7, indicating that China has continuously improved its R&D efficiency in the past ten years. The contribution rate of R&D efficiency to the change in green patents from 2003 to 2004 is negative; both innovation activities and innovation efficiency were affected, where the 2003 SARS outbreak might also have had an influence. The downwind pressure on China's economic development may have caused the negative effect of R&D efficiency in 2013-2014. Although the effect of R&D efficiency fluctuated during the study period, it showed an overall upward trend, indicating that the efficiency of green technology innovation in China was consistently improving. R&D investment was more effectively used, which also benefits from a series of technological innovation incentive policies that China implemented.

Notably, R&D effects (i.e., R&D reaction effect and R&D efficiency effect) played a dominant role in the increased number of green patent applications. Figure 5 demonstrates that the two effects' contribution rate shows approximately the same trend. Therefore, increasing investment in R&D activities and improving R&D efficiency are of substantial significance to improving the output of green technology innovation in China.

(5) *Green Patent Share Effect.* The green patent share effect also plays a positive role in promoting green technology innovation. Although the effects of green patents fluctuated during the study period (and even showed negative values in specific years), the overall trend was upward. The maximum value was 10523.8 in 2013-2014, and the minimum value was 146.9 in 2004-2005. This indicates that the proportion of green technology innovation output was increasing with the rising market demand for green technology products and the growing importance of green technology innovation.

5. Conclusions and Implications

5.1. Conclusions. This study has examined the main influencing factors contributing to green patent applications in China from 2000 to 2017. We developed the extended LMDI method to decompose and analyze the contributions of the main influencing factors, which include economic scale, carbon emission intensity, R&D reaction, R&D efficiency, and green patent share factors. The main conclusions are as follows.

First, taking the number of green patent applications as an indicator for green innovation output and based on the statistical data from 2000 to 2017, the number of green patent applications in China showed an upward trend—especially after 2010, maintaining rapid growth.

Second, the results of the LMDI additive decomposition based on the period-wise manner indicate that all of the factors, except the carbon emission intensity effect, are positive factors on the growth of China's green patent applications. Of these positive factors, the R&D efficiency effect and economic scale effect contribute the most to the growth of China's green technology patents. Among the positive and negative effects, R&D efficiency and carbon emission intensity effect are the most prominent, which indirectly reflects modern climate change and environmental deterioration; that is, improving R&D efficiency and reducing carbon emissions are important measures to promote China's green technology innovation.

Third, the year-by-year decomposition analysis results show that all influencing factors contributed differently to the change in green patent applications in various years and grew involved in largely disparate influence with respect to time series. In most years, carbon emission intensity has a negative impact on green patent applications. Notably, the contribution rate of R&D reaction effect and R&D efficiency effect shows approximately the same trend, and the two effects played a dominant role in the increased number of green patent application.

5.2. Policy Implications. From the previously mentioned findings, we can better understand the trend of China's green technology innovation and clarify the importance of carbon emissions, R&D efficiency, economic development, and other factors for green technology innovation. We can then formulate targeted management policies, governance measures, and R&D strategies. Based on these conclusions, we propose the following policy recommendations.

First, China must accelerate the construction of a market-oriented green technology innovation system and promote the development of green technology innovation activities. With increasingly prominent domestic environmental problems and the ongoing pressure of international climate negotiations (e.g., *Kyoto Protocol* and *Paris Agreement*), international green competition is likely to change the current national comparative advantage. To solve practical problems, undertake international obligations, and enhance international competitiveness, China must accelerate the construction of a market-oriented green

technology innovation promotion system. In May 2019, the National Development and Reform Commission and the Ministry of Science and Technology jointly issued the Guiding Opinions on the Construction of Market-Oriented Green Technology Innovation System. This was the first instance in which China published opinions on how to construct a system for green technology innovation, and the system is of considerable value. The system suggested the government formulate a series of policies to guide, stimulate, and guarantee (1) green technology innovation, such as financial measures as well as science and technology policies and the popularization and application of achievements; (2) policies to encourage green production and the green transformation and upgrading of industries; and (3) green financial policies and green import and export policies to stimulate innovation subjects' enthusiasm and to improve the quality of green innovation.

Second, China should increase investment in green technology R&D to improve R&D efficiency. This study demonstrates that R&D factors, especially R&D efficiency, are important factors affecting the output of green technology innovation. Although China's R&D investment has been increasing in recent years due to its large-scale market, the investment is too scattered, and most enterprises' R&D expenditure is relatively low. Therefore, the government should increase R&D investment related to the environment and designate relevant incentive mechanisms so that enterprises can actively become the source of R&D funds and the main body of implementation.

Third, China needs to improve environmental regulatory policies and accelerate innovation in environmental regulatory tools. As opposed to previous studies, which mainly considered the impact of environmental regulation on green technology innovation, this study included carbon emissions in the decomposition framework of innovation output in the green technology department. The study found the intensity of carbon emissions inhibited the output of green technology innovation. Therefore, China still must strengthen environmental regulation, reduce carbon emission intensity, and balance environmental protection and economic development. Enterprises should be encouraged to carry out green technology innovation by further improving environmental regulation policies, innovating environmental regulation tools, and using diversified environmental regulation methods. At the same time, China should pay attention to strengthening the cooperation between environmental regulation policy tools and relevant policies (such as finance and innovation policies).

Finally, China must strengthen the protection of intellectual property rights. The primary objectives are to take the strictest measures to protect intellectual property rights, reduce the risk of infringement on enterprises' R&D investment, maintain and protect the achievements and benefits of enterprise green technology innovation, and fully mobilize enterprise enthusiasm for green technology innovation.

We believe the novel decomposition analysis applied in this study is useful for understanding changes in green patent application activities in China. Additionally, a

comparison of carbon intensity effect, R&D reaction effect, and R&D intensity effect are helpful for understanding the influencing factors of green technology innovation. A limitation of this study is the difficulty of clarifying the effects of policies and subsidies on green technology innovation activities. Therefore, further research is needed to develop a research framework to consider the previously mentioned factors. In addition, the green patent includes numerous types of green technologies; thus, further studies are needed to consider various green patent classifications.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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