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The role of green technology innovation on employment: does industrial structure optimization and air quality matter?

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Abstract

Although green technology innovation is an important means to balance the environment and economy, few studies have analyzed the employment effects of green technology innovation in developing countries. Therefore, this paper employs the panel data of 286 prefecture-level cities in China from 2006 to 2017 to empirically test the impact of various green technology innovations on urban employment. Meanwhile, from the perspectives of air quality and industrial structure optimization, the influencing mechanism of green technology innovation on employment is deeply analyzed. The results reveal that all kinds of green technology innovation can significantly increase the employment level of the city, and the promotion effect is strongest in the 2nd year after the patent application. According to the results of heterogeneity analysis, key cities of environmental protection and non-resource cities are more likely to generate positive employment effects through green technology innovation. Finally, the mediation effect test model confirms that green technology innovation can promote employment by improving air quality and causing industrial structure optimization.

Keywords Green technology innovation, Urban employment, Employment effect, Developing countries, Air quality, Industrial structure optimization

Introduction

After entering the twenty-first century, the world is facing a continuous increase in the threat to the ecological environment. The way of economic development at the expense of the environment has been widely criticized, while sustainable green development has become a common choice for human beings to deal with the problems of energy shortage, environmental degradation and climate change. As green technology has the characteristics of improving energy efficiency and reducing pollution emissions, many scholars believe that green technology innovation is an important means to achieve green development [5]. According to statistics [54], the number of global green technology patent applications from 2016 to 2022 has reached 1.047 million, showing a steady growth trend. Among them, China's leading enterprises are one of the main contributors. However, due to the high degree of substitutability between green technology and non-green technology, most enterprises are forced to carry out green technology innovation under external policy intervention [2]. Neoclassical economics believes that strict environmental regulation measures will increase the production cost of enterprises. Meanwhile, technological progress is usually assumed to substitute labor input to some extent. Therefore, people will worry that green technology innovation will threaten their employment problems.

At present, China is in the final stage of leaping the middle-income trap. Therefore, the Chinese government urgently needs to promote green technology innovation

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to support the new development path to achieve economic growth and environmental protection. However, different from other countries, the Chinese government generally adopts process-based policies to directly intervene in the development of green technology innovation. Although the short-term effect of direct intervention is obvious, the effective period is short and it is easy to cause fluctuations in production and market later. Meanwhile, under the impact of the COVID-19 pandemic, China's economy is slowing down and the employment situation is becoming more severe. According to China's National Bureau of Statistics [13], the number of employed people in 2022 will be 734 million, a decrease of 3% compared with 2018. Therefore, clarifying the impact of green technology innovation on employment has become an issue of practical significance. There is relatively little literature on the link between green technology innovation and employment. Among them, mainstream studies believe that the impact of green technology innovation is positive [25]. Empirical evidence mainly comes from the data of developed countries such as Europe and the United States [4, 35], but lack of research on developing countries. From the research level, they tend to focus on the industry and enterprise level [24, 40], but lack analysis of urban employment. Meanwhile, when they study the impact of different types of green technology innovation on labor demand, they are used to categorize green technology innovation into product innovation and process innovation. In fact, according to the United Nations Framework Convention on Climate Change (UNFCCC), green technology innovations are patents related to Environmentally Sound Technologies. Green technology innovation can be roughly divided into seven types based on IPC classification numbers. Therefore, this paper puts the research background in China and focuses on analyzing the impact of heterogeneous green technology innovation on urban employment. Specifically, this paper uses panel data of 286 prefecture-level cities in China from 2006 to 2017 to empirically test the impact of green technology innovation on urban employment.

The main contributions of this paper are as follows: Firstly, this paper is the first to examine the employment effects of green technology innovation by using data at the prefecture level in China. It provides evidence and new ideas for developing countries, including China, to realize the balanced development of the environment and economy. Secondly, when analyzing the impact of heterogeneous green technology innovation on employment, this paper divides green technology innovation into seven types: alternative energy production, transportation, energy conservation, waste management, agriculture or forestry (carbon emission storage), administration, management and design aspects, and nuclear power generation. It helps to accurately identify the impact of various environmentally sound technologies on employment. Thirdly, this paper analyzes how green technology innovation affects labor supply and demand from the perspectives of air quality and industrial structure optimization. It contributes to understanding how green technology innovation affects employment.

The following chapters are arranged as follows: the second and third parts are literature review and theoretical analysis respectively; Then there are the methods and data; The fifth part is the analysis and discussion of the empirical results. The final part is the conclusion and policy enlightenment.

Literature review

A large number of academic studies have demonstrated that innovation and its subsequent application and promotion are closely related to employment. More scholars believe that whether innovation is labor-friendly depends on the perspective and level of research, the type of innovation, and the sector that generates innovation [14]. Dosi et al. [16] constructed a two-sector economic model to explain the dynamic relationship between technological progress and employment. Their study found that disembodied technological innovation—R&D investment or patents—has a facilitative effect on employment in the upstream sector, while expansionary investment has a positive effect on the downstream sector. Mondolo [42] argued that technological change can optimize the allocation of labor force, which may eliminate low-skilled workers and technologically backward sectors and enterprises, but also benefit subjects with new technologies.

In addition, with the application and development of 5G, big data and artificial intelligence, many scholars have also theoretically and empirically examined the impact of electronic information technology progress on employment [1]. However, the research of Li et al. [37] shows that the application of robots has increased the labor demand of Chinese enterprises. It can be seen that there is significant heterogeneity in the employment effect of technological innovation.

At present, there are few studies on the impact of green technology innovation on job creation. Most of them revolve around developed economies such as Europe and the United States. Pfeiffer and Rennings [47] and Horbach [28] both used data from German industrial enterprises and confirmed that green technology innovation, like other innovations, can significantly improve the demand for highly skilled labor. Kunapatarawong and Martinez-Ros [34] reached similar conclusions in their empirical analysis of data from the Spanish Technology Innovation Group (PITEC), and found that the employment effect of green technology innovation was more obvious in enterprises in "polluting industries.

Further studies point out that the effect of green technology innovation on employment will be affected by various factors. In terms of green technology innovation types, cleaner production technologies are more conducive to job creation than end-of-pipe technologies [47, 50]. Rennings et al. [51] and Horbach [28] argued that eco-innovations in products and services have a positive impact on employment, while the opposite is true for end-pipeline technologies. For the purpose of green technology innovation, green technology innovation aimed at improving the competitiveness of enterprises and increasing market share can effectively expand the internal employment demand [27]. Conversely, if firms pursue green technology innovation with the aim of reducing costs, the impact on employment is negative [50]. Additionally, many scholars have noticed that green technology innovation has an obvious spatial spillover effect [46], which has a positive effect on the employment level of enterprises [4].

Recent research has focused on the employment impact of renewable energy development (one of the green technology innovations). For example, Ram et al. [49] indicate that renewable energy generation technology will become an important job creator in the twenty-first century. In an empirical study of the development of the green energy sector in 18 OECD member countries, Destek et al. [15] found that green energy consumption reduced the unemployment rate in Canada, France, Israel, Mexico and New Zealand. Kumar et al. [33] also reached a similar conclusion in their study on India. Correspondingly, the study of Naqvi et al. [43] shows that the development of renewable energy technology can provide more jobs and alleviate the unemployment rate in EU countries.

To sum up, the existing literature has the following defects: Firstly, most studies focus on developed economies such as Germany and the United States, and there is a lack of empirical analysis of developing countries. Secondly, scholars tend to examine the employment effect of green technology innovation at the enterprise or industry level, but ignore the analysis at the city level. The changes in micro individual enterprises do not reflect the overall effect on society. Thirdly, the classification of green technology innovation is limited to product innovation and technological innovation, which cannot further reflect the heterogeneous impact of various green technologies on the labor force. Therefore, this paper aims to fill the gaps in the existing literature and provide new evidence for addressing environmental and employment issues in developing countries.

Theoretical analysis and research hypotheses

The employment effect of green technology innovation

Through literature review, this paper argues that green technology innovation affects employment mainly by triggering price and quantity changes. Specifically, this paper discusses the potential impact of green technology innovation on employment in three scenarios.

The first scenario is when green technology innovation is presented as a new technology. Firstly, the application of new technology needs to be equipped with new technical personnel to operate and manage it. That creates demand for new jobs. However, the application of new technology may require the purchase of new instruments and accessories, which will increase the production cost of enterprises and affect the final product price. Higher product prices will lead to lower demand, which will eventually reduce employment. Secondly, green technology innovation generally improves the efficiency of energy and material production. The improvement in efficiency means that the input of energy and materials is saved while the output is unchanged. Cost reduction will affect the market price of products, which in turn will increase the market demand for products and increase employment. However, the improvement of internal efficiency may replace part of the labor force, which in turn will reduce the demand for labor and have a negative impact on employment.

The second scenario is when green technology innovation is presented as a new product. The creation of new products will directly create new jobs. Demand for new products will further boost demand for labor. However, new green products may replace traditional environmentally unfriendly products, reducing the demand for these backward products and thus the demand for labor.

In addition, if the development of new green products eventually becomes a monopoly, it will lead to higher product prices and lower production [23]. Ultimately, it will have a negative impact on employment.

The third scenario is when green technology innovation is presented as an innovation in administrative management. Taking the carbon emission trading mechanism as an example, it has an impact on enterprises' green innovation activities and production activities mainly through two channels [61]. On the one hand, the carbon emission trading mechanism will increase the production cost of enterprises, restrict the investment in technology research and development and the expansion of production scale, thus reducing employment. On the other hand, the carbon emission trading mechanism can not only optimize the innovation process for enterprises and improve production efficiency, but also bring environmental and economic benefits, thus stimulating employment.

Although this paper discusses the impact of green technology innovation on employment in three scenarios, in real life, a new green technology will trigger a series of changes in production and consumption structure. Thus, each green technology innovation can simultaneously affect employment through several of the above-mentioned pathways. The overall effect of green technology innovation on employment is difficult to get answered through theoretical analysis, so an empirical investigation is needed. Accordingly, this paper puts forward the following hypotheses.

Hypothesis 1 There is a significant association between green technology innovation and its subcategories and urban employment level, but its affected direction is not clear.

Green innovation, air quality, and employment

One important mechanism by which green technology innovation affects jobs is through improved air quality. Many studies have confirmed that green technology innovation can significantly reduce the emission of air pollutants by improving energy use efficiency, changing energy consumption structure, and disposing of terminal wastes [17, 44, 58, 59]. Air quality is one of the important factors affecting the location of labor employment [11, 36, 53, 65]. Air quality not only directly affects the physical and mental health of workers [8, 10] but also indirectly affect their subjective well-being and behavioral decision-making [3, 62, 63]. The poor air quality will harm the physical and mental health of residents, affect the efficiency of individual labor, and ultimately have a negative impact on labor supply [6, 9, 38, 48, 62, 63]. Therefore, the improvement of air quality brought about by green technology innovation can not only reduce the tendency of local labor to emigrate but also increase the willingness of external labor to migrate. Eventually, it will help supply local Labour. Based on the above analysis, the second hypothesis of this paper is proposed.

Hypothesis 2 Green technology innovation promotes employment by improving urban air quality and increasing labor supply.

Green innovation, industrial structure optimization, and employment

Another mechanism through which green technology innovation affects employment is industrial structure optimization. Firstly, green technology innovation can improve the efficiency of resource consumption and reduce environmental pollution, thereby reducing the cost of production and terminal treatment of enterprises [39, 57, 64]. A fall in costs will lead to a fall in product prices. And the market demand for this product will also increase with the decrease in the product price. Secondly, with the enhancement of consumer awareness of environmental protection, the market demand for green products is also increasing [30]. In other words, consumers are more willing to pay for green-produced products [66]. The application of green technology innovation can improve the competitiveness of products and expand the market demand. Therefore, in order to meet the market demand, enterprises will expand the production of products. At the same time, it will increase its demand for labor. Eventually, this will lead to an increase in the demand for labour. It can be said that green technology innovation changes the industrial structure optimization by causing demand changes, thus affecting employment [19, 45]. Furthermore, compared with the tertiary industry, the secondary industry, especially the manufacturing industry, will bring greater threats to the environment [52]. As a result, labour demand in secondary industries may be more sensitive to green technology innovation. Therefore, the third hypothesis is proposed.

Hypothesis 3 Green technology innovation promotes employment by influencing the industrial structure optimization and increasing labor demand.

Methods and data

Econometric model

To estimate the impact of green technology innovation on urban employment levels, this paper uses the following two-way fixed effects model as a benchmark regression:

$$\mathrm{lnEmp}_{\mathrm{i,t}} = \alpha_0 + \alpha_1 \mathrm{lnGIPC}_{\mathrm{i,t}} + \alpha_2 \mathrm{X}_{\mathrm{i,t}} + \mu_{\mathrm{i}} + \gamma_{\mathrm{t}} + \varepsilon_{\mathrm{i,t}} \tag{1}$$

where i stands for city, t stands for year; lnEmp is the employment level; lnGIPC stands for green technology innovation; X is a set of control variables, including economic development level (lnED), human capital (lnHC), industrial structure (lnIS), population size (lnPS), capital stock (lnCS), and use of foreign capital (lnFC); μ_i and γ_t are city fixed effects and year fixed effects respectively; $\varepsilon_{i,t}$ is the random error term.

Explained variable

Most works of literature generally use an employment growth rate [25] to measure job creation, and the total number of employees or R&D personnel to measure employment level [26]. Since this article focuses on employment levels at the city level, persons employed in urban units at the end of the year are used as a proxy variable.

Main explanatory variables

Green innovation is the main explanatory variable concerned in this paper, which is generally measured from the perspective of input or output. Research commonly uses indicators such as environment-related R&D investment, sales of new products, or the number of green patents [18, 56]. But R&D investment and new product sales are more applicable to firm-level research. Some scholars construct a comprehensive index to measure green technology innovation according to the information from the survey report [34], but there are subjective effects on the assignment of weights. Therefore, the green patent is a good choice to measure urban green technology innovation. Previous studies believed that the identification and definition of green patents were not clear enough, which affected the credibility of conclusions [32]. At present, the World Intellectual Property Organization (WIPO) has clearly defined green patents as those related to environmentally sound technologies. Meanwhile, due to the uncertainty of patent approval time, the number of patent applications can better reflect the green technology innovation level of the year [7].

Specifically, according to the IPC Green patent list issued by WIPO, this paper screened out the green-related parts (lnGIPC) from all patent applications. Further, according to the IPC classification, green patents are divided into alternative energy production (lnGIPC1), transportation (lnGIPC2), energy conservation (lnGIPC3), waste management (lnGIPC4), agriculture or forestry (lnGIPC5), administrative, management or design aspects (lnGIPC6), nuclear power generation (lnGIPC7) these seven types (see Appendix 1).

Control variables

In addition to controlling the characteristics that do not change with time and cities, this paper also adds some additional indicators as control variables to reduce the endogeneity of the model. The control variables at the city level include the level of economic development (lnED), human capital (lnHC), industrial structure (lnIS), population size (lnPS), capital stock (lnCS), and use of foreign capital (lnFC) [21, 46]. Specifically, per capita GDP is used to measure the level of economic development, The ratio of the number of university students to the total urban population is used to reflect the human capital; The industrial structure is expressed by the ratio of the added value of the secondary industry and the tertiary industry; Population size is measured by the average annual population; Referring to the method of Meng and Qu [41], capital stock is replaced by fixed asset investment (using the "perpetual inventory method", the price reduction is carried out with 2000 as the base period, and capital depreciation rate is set at 9.6%),The use of foreign capital is measured by the ratio of foreign direct investment to GDP.

Data sources

This paper uses panel data from 286 prefecture-level cities in China from 2006 to 2017. The study period ends in 2017 because the patent data is only available until this year. Unlike most articles that use CIS (Community Innovation Surveys) data from European countries, this paper applies green patent data from China's State Intellectual Property Office. The rest of the data are from the China Urban Statistical Yearbook. Missing data were supplemented by linear interpolation.

Table 1 reports descriptive statistics for the variables. In order to reduce the influence of heteroscedastic property and zero value on the regression results, all variables were processed by adding 1 and taking the natural logarithm. The variance inflation factor (VIF) test is further conducted (see Appendix 2), and the result shows that there is no multicollinearity problem among the variables.

Analysis and discussion of empirical results

Baseline regression analysis

In order to verify that the two-way fixed effects model selected in this paper meets the requirements, the following preliminary tests are made. Firstly, the Hausmann test proves that the fixed effect model is more suitable than the random effect model. Secondly, the joint significance

Table 1 Descriptive statistics

Variable	Obs	Mean	Std. dev	Min	Max
lnEmp	3432	3.557945	0.8057739	0	6.895551
lnGIPC	3432	3.876681	1.841369	0	9.845011
lnGIPC1	3432	2.711313	1.647193	0	8.24722
lnGIPC2	3432	1.676714	1.517276	0	6.835185
lnGIPC3	3432	2.367334	1.831381	0	8.937744
lnGIPC4	3432	2.551078	1.802805	0	8.208491
lnGIPC5	3432	0.6892097	0.9627814	0	4.691348
lnGIPC6	3432	1.483619	1.664537	0	8.583168
lnGIPC7	3432	1.224746	1.391573	0	6.628041
lnED	3432	10.29142	1.064273	0	15.6752
lnHC	3432	0.0162732	0.0218047	0	0.1350376
lnIS	3432	0.838688	0.2524185	0	2.45172
lnPS	3432	5.841594	0.7674129	0	8.129175
lnCS	3432	16.60361	2.457789	0	20.05556
lnFC	3432	1.376364	0.818212	0	4.152794

test for all year dummy variables strongly rejects the null hypothesis of "no time effect".

Table 2 shows the regression results of Eq. (1). Regardless of whether control variables are added, the effect of green technology innovation on employment is significantly positive at the 1% confidence level. The coefficient of lnGIPC in column (2) is 0.052, indicating that a 1% increase in the number of green patents will increase employment by 5.2%. Overall, it means that green technology innovation can create new jobs and significantly boost urban employment in China.

Furthermore, the results from columns (3) to (9) indicate that the impact of various green technology innovations on employment remains remarkably positive at the 1% confidence level. However, as can be seen from the coefficient, the effect intensity of various green patents

Table 2 Baseline regression

Variables	(1) GIPC	(2) GIPC	(3) GIPC1	(4) GIPC2	(5) GIPC3	(6) GIPC4	(7) GIPC5	(8) GIPC6	(9) GIPC7
lnGIPC	0.056***	0.052***							
	(5.12)	(4.77)							
lnED		0.003	0.005	0.005	0.005	0.004	0.004	0.005	0.005
		(0.29)	(0.41)	(0.47)	(0.39)	(0.38)	(0.38)	(0.45)	(0.48)
lnHC		1.382	1.369	1.232	0.948	1.228	0.949	0.627	1.156
		(0.77)	(0.75)	(0.68)	(0.52)	(0.68)	(0.51)	(0.34)	(0.64)
lnIS		0.254***	0.264***	0.262***	0.268***	0.265***	0.267***	0.257***	0.280***
		(3.68)	(3.78)	(3.70)	(3.81)	(3.72)	(3.70)	(3.55)	(3.92)
lnPS		0.087*	0.087*	0.088*	0.090*	0.087*	0.088*	0.091*	0.088*
		(1.81)	(1.81)	(1.81)	(1.87)	(1.79)	(1.83)	(1.90)	(1.83)
lnCS		− 0.185***	− 0.187***	− 0.175**	− 0.181**	− 0.186***	− 0.181**	− 0.171**	− 0.187***
		(− 2.70)	(− 2.72)	(− 2.48)	(− 2.58)	(− 2.65)	(− 2.55)	(− 2.43)	(− 2.66)
lnFC		0.003	0.003	− 0.002	0.000	0.001	0.001	− 0.002	0.001
		(0.34)	(0.30)	(− 0.19)	(0.04)	(0.12)	(0.08)	(− 0.20)	(0.07)
lnGIPC1			0.045***						
			(5.39)						
lnGIPC2				0.034***					
				(3.92)					
lnGIPC3					0.036***				
					(4.08)				
lnGIPC4						0.036***			
						(4.38)			
lnGIPC5							0.038***		
							(3.63)		
lnGIPC6								0.048***	
								(5.03)	
lnGIPC7									0.028***
									(4.44)
Constant	3.210***	5.323***	5.385***	5.238***	5.321***	5.403***	5.363***	5.173***	5.414***
	(94.46)	(5.60)	(5.65)	(5.43)	(5.52)	(5.60)	(5.49)	(5.42)	(5.60)
Observations	3432	3432	3432	3432	3432	3432	3432	3432	3432
R-squared	0.409	0.448	0.449	0.444	0.445	0.445	0.445	0.452	0.443
Number of cities	286	286	286	286	286	286	286	286	286
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses

*** $p < 0.01$

** $p < 0.05$

* $p < 0.1$

on the employment level is different. Green patents in "Administrative, management or design aspects" (GIPC6) have the strongest employment promotion effect. For every additional unit of a patent application, employment increases by 0.048. It shows that green technology innovation in administrative management can effectively alleviate unemployment. In fact, the application of green management in enterprises can not only effectively reduce waste discharge, which will reduce the cost of pollution abatement, but also improve the reputation of enterprises, which will eventually expand the market size of enterprises and increase the demand for labor [31]. Second is the green patent for "alternative energy production" (GIPC1). Each additional unit of patent application leads to a 0.045 increase in the employment level. It indicates that the development of alternative energy technology can create jobs and have a positive impact on China's job market. Naqvi et al. [43] have similar findings. This may be related to the rapid development of clean energy technologies in China in recent years, especially solar, hydrogen and wind energy. The employment effect is relatively weak in green patent applications for "nuclear power generation" (GIPC7). its contribution to the employment level is less than 0.03.

In addition, we observe that the industrial structure expressively increases employment at the 1% confidence level. Population size is also an important factor affecting the size of employment. The coefficient on the effect of population size on the number of employed people is approximately 0.087 to 0.09 (at the 10% confidence level). However, the capital stock significantly reduces the level of employment at a confidence level of at least 5%. Each unit increase in the capital stock causes a decline in employment in the range of 0.17 to 0.19. As for the remaining control variables, their influence on the dependent variable is not significant.

Table 3 The endogeneity problem

Variables	(1) First stage lnGIPC	(2) Second stage lnEmp	(3) SysGMM
L1_lnGIPC	0.272***		
	(10.63)		
L2_lnGIPC	0.113***		
	(4.93)		
lnGIPC		0.165***	0.089***
		(6.64)	(4.11)
L.lnEmp			0.798***
			(15.29)
Observations	2860	2860	2860
R-squared		0.358	
Number of citycode	286	286	286
Control variables	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Underidentification test		0.000	
Weak identification test		110.1	
Stock-Yogo bias critical value		19.93(10%)	
AR(1)			0.001
AR(2)			0.137
Hansen Test			0.117
Wald			661,742

z-statistics in parentheses

*** $p < 0.01$

The endogeneity problem

An important issue needed to be addressed is the possible endogeneity problem. There are two main reasons for endogeneity. Firstly, there may be reverse causality between green technology innovation and employment level. Secondly, the current employment level will be affected by the inertia of the previous period. Hence, this paper uses two approaches to alleviate the endogeneity problem.

Firstly, this paper refers to the method of Xu et al. [58] and uses the first-order and second-order lag terms of green technology innovation (L1_lnGIPC and L2_lnGIPC) as instrumental variables. Although GMM is the more efficient estimator, 2SLS can be used for both overidentification and just-identification. Therefore, 2SLS is applied. Column (1) of Table 3 represents the results of the first-stage regression. According to the coefficients, both instrumental variables promote green technology innovation at the 1% confidence level. Column (2) reports the second-stage regression results, which are consistent with the baseline estimates. Green technology innovation does have a significant positive effect on employment levels (at 1% confidence level). In addition, unidentifiable tests and weak instrumental variable tests confirm the validity of instrumental variables.

Secondly, referring to the method of Lachenmaier and Rottmann [35], the first-order lag term of the explained variable is introduced to form the dynamic panel model. Then, the system GMM estimator is used. As the coefficient in column (3) of Table 3 shows, the coefficient on green technology innovation still remains positive at the 1% confidence level. In addition, the test results reveal that the difference of the error term has first-order autocorrelation, but no second-order autocorrelation. Meanwhile, the result of the overidentification test proves that the null hypothesis of "all instrumental variables are valid" can be accepted at 10% confidence level.

Robustness test

In order to further confirm the reliability and consistency of the evaluation results, this paper also adds some robustness tests. The regression results are reported in Table 4. Firstly, column (1) adopts the method of reducing the sample size. In China, the political level of cities from top to bottom is divided into municipalities directly under the Central Government, sub-provincial cities, non-sub-provincial capital cities, and ordinary prefecture-level cities. High-grade cities usually have priority in the distribution of important production factors, such as human resources [29]. Therefore, 19 cities at the sub-provincial level and above were removed from the sample. Then, considering that this paper uses the application data of green patents, the employment effect will have a lagged effect. So, the number of green patent applications is replaced by its first-, second-, and third-period lag term respectively (L1_lnGIPC, L2_lnGIPC and L3_lnGIPC). The regression results are reported in columns (2) to (4). Observing the coefficients in Table 4, it can be asserted that the promoting effect of green technology innovation on the employment level is robust. At the same time, we find that the employment promotion effect of green patents is strongest in the 2nd year after the application is filed.

Table 4 Robustness test

Variables	(1) Excluded	(2) Lag1	(3) Lag2	(4) Lag3
lnGIPC	0.050***			
	(4.60)			
L1_lnGIPC		0.050***		
		(4.55)		
L2_lnGIPC			0.053***	
			(5.00)	
L3_lnGIPC				0.049***
				(4.22)
Constant	4.526***	4.893***	4.417***	3.669***
	(4.52)	(5.32)	(4.86)	(3.94)
Observations	3204	3146	2860	2574
R-squared	0.445	0.440	0.428	0.390
Number of citycode	267	286	286	286
City FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses

*** $p < 0.01$

Heterogeneity test

There are significant differences between Chinese cities in terms of policy background, resources, and environment. Therefore, we need to discuss the heterogeneity of the urban sample.

Firstly, the implications of the policy context should be considered. The State Council (2007) named 113 cities in The 11th Five-Year Plan for National Environmental Protection that needed to focus on air pollution control. Generally, cities that are paid more attention by the central government have more motivation and an urgent need to develop green technology innovation, no matter what their purpose is. Some studies have argued that proactive green technology innovation activities will bring more positive employment effects [27]. Therefore, columns (1) and (2) in Table 5 divide the sample into key cities of environmental protection and non-key cities of environmental protection.

By comparing the coefficient of lnGIPC, it can be seen that the effect of green technology innovation on employment level is stronger in key cities of environmental protection. At the 1% confidence level, each additional unit of green technology innovation can lead to 7.5% employment growth in key environmental protection cities, but only 4.7% growth in non-key environmental protection cities. It shows that green technology innovation can bring more significant employment effects driven by the policies of the central government. Kunapatarawong & Martinez-Ros [34] hold the similar idea.

Secondly, we consider the differences between cities in terms of resources and environment. According to the National Sustainable Development Plan for Resource-based Cities (2013–2020) issued by The State Council [55], 126 prefecture-level cities are resource-based cities. Studies have demonstrated that many resource-based cities are facing resource curse problems such as resource exhaustion, economic recession, and unemployment, and there is an urgent need for green transformation [12, 20]. Therefore, columns (3) and (4) in Table 5 divide the sample into resource-based cities and non-resource-based cities to compare the heterogeneous effect brought by green technology innovation.

The regression results show that the coefficient of green technology innovation (lnGIPC) remains meaningfully positive at 1% confidence level for both resource-based and non-resource-based cities. However, the employment promotion effect of non-resource-based cities is stronger, while that of resource-based cities is weaker. The authors believe that the possible reason is that resource-based cities have a single industrial structure and generally have a high degree of dependence on resource-based industries. Therefore, path dependence and resource dependence will hinder the transformation

Table 5 Heterogeneity test

Variables	(1) EPCity	(2) Non-EPCity	(3) ResourceCity	(4) Non-ResourceCity
lnGIPC	0.075***	0.047***	0.041***	0.052***
	(3.97)	(3.60)	(2.92)	(3.22)
lnED	0.026	– 0.007	0.011*	0.002
	(1.47)	(– 0.84)	(1.67)	(0.17)
lnHC	– 0.123	6.554	– 4.566	1.108
	(– 0.12)	(0.72)	(– 1.50)	(0.64)
lnIS	0.322***	0.229***	0.141**	0.263**
	(2.79)	(2.83)	(2.08)	(2.26)
lnPS	0.039	0.160*	0.110	0.078
	(0.97)	(1.76)	(1.41)	(1.35)
lnCS	– 0.294**	– 0.079	– 0.050	– 0.249**
	(– 2.57)	(– 1.10)	(– 0.73)	(– 2.55)
lnFC	– 0.012	0.015	0.021	0.002
	(– 0.90)	(1.08)	(1.23)	(0.17)
Constant	7.531***	3.058**	2.968***	6.570***
	(5.06)	(2.53)	(3.21)	(5.08)
Observations	1356	2076	1380	2052
R-squared	0.582	0.390	0.329	0.527
Number of citycode	113	173	115	171
City FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses

*** $p < 0.01$

** $p < 0.05$

* $p < 0.1$

and upgrading of industrial structure to the green direction, thus reducing the employment effect of green technology innovation.

Mechanism analysis

Next, we examine the impact mechanism of green technology innovation and its subcategories on urban employment. The "three-step method" is widely used in the existing literature to test the mediating effect, and the specific model is as follows:

$$\mathrm{lnEmp}_{i,t} = \delta_0 + \delta_1 \mathrm{lnGIPC}_{i,t} + \delta_2 X_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (2)$$

$$M_{i,t} = \beta_0 + \beta_1 \mathrm{lnGIPC}_{i,t} + \beta_2 X_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (3)$$

$$\begin{aligned}\mathrm{lnEmp}_{i,t} = &\gamma_0 + \gamma_1 \mathrm{lnGIPC}_{i,t} + \gamma_2 M_{i,t} \\ &+ \gamma_3 X_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}\end{aligned} \quad (4)$$

where, $M_{i,t}$ is the mediating variable, including air quality and industrial structure. Air quality is measured by the concentration of PM2.5 in prefecture-level cities. The industrial structure is still measured by the ratio of the added value of the secondary industry and the tertiary industry. The δ_1 is the total effect of green technology innovation on the employment level, while γ_1 is the direct effect; The mediating effect is the product of the β_1 and γ_2. If δ_1, β_1, γ_1, and γ_2 are all significant, the mediating effect is significant. If δ_1, β_1, and γ_1 are significant but γ_2 is not, the full mediating effect is proved to be significant. Additionally,$\beta_1\gamma_2/\delta_1$ can measure the relative size of the mediating effect.

Table 6 (including table 8–1 to 8–4) lists the analysis results of the mediating effect of air quality. It can be seen that the mediating effect of air quality is significant. According to the results in columns (1) to (3), an improvement in air quality can increase the employment level by 0.0024 at the 1% confidence level. Hence, it can be said that green technology innovation can improve the air quality of cities and increase the livability of cities, thus attracting the inflow of labor. Additionally, previous literature has verified the promoting effect of air quality improvement on employment [60]. Column (2) of Table 6 shows that green technology innovation can

Table 6 The mediating effect of air quality

Variables	**(1)** **Emp**	**(2)** **PM2.5**	**(3)** **Emp**	**(4)** **Emp**	**(5)** **PM2.5**	**(6)** **Emp**
lnGIPC	0.056***	− 0.020***	0.054***			
	(5.09)	(− 2.69)	(5.04)			
lnPM25			− 0.120***			− 0.124***
			(− 2.87)			(− 2.95)
lnGIPC1				0.047***	− 0.011	0.045***
				(5.63)	(− 1.58)	(5.64)
lnGIPC2						
lnGIPC3						
lnGIPC4						
lnGIPC5						
lnGIPC6						
lnGIPC7						
Constant	4.738***	4.249***	5.248***	4.780***	4.230***	5.305***
	(5.35)	(13.47)	(5.81)	(5.39)	(13.32)	(5.86)
Observations	3432	3432	3432	3432	3432	3432
R-squared	0.438	0.149	0.442	0.438	0.146	0.443
Number of citycode	286	286	286	286	286	286
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Variables	**(7)** **Emp**	**(8)** **PM2.5**	**(9)** **Emp**	**(10)** **Emp**	**(11)** **PM2.5**	**(12)** **Emp**
lnGIPC						
lnPM25						
			− 0.123***			− 0.124***
lnGIPC1			(− 2.82)			(− 2.87)
lnGIPC2						
	0.037***	− 0.015***	0.035***			
lnGIPC3	(4.09)	(− 3.04)	(3.96)			
				0.037***	− 0.013**	0.035***
lnGIPC4				(4.19)	(− 2.56)	(4.19)
lnGIPC5						
lnGIPC6						
lnGIPC7						
Constant						
	4.627***	4.301***	5.156***	4.706***	4.261***	5.237***
	(5.17)	(13.57)	(5.62)	(5.25)	(13.51)	(5.70)
Observations						
R-squared	3432	3432	3432	3432	3432	3432
Number of cities	0.433	0.148	0.438	0.433	0.147	0.438
City FE	286	286	286	286	286	286
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Variables	Yes	Yes	Yes	Yes	Yes	Yes
Variables	**(13)** **Emp**	**(14)** **PM2.5**	**(15)** **Emp**	**(16)** **Emp**	**(17)** **PM2.5**	**(18)** **Emp**
lnGIPC						
lnPM25						
			− 0.124***			− 0.127***

Table 6 (continued)

Variables	(13) Emp	(14) PM2.5	(15) Emp	(16) Emp	(17) PM2.5	(18) Emp
lnGIPC1			(– 2.83)			(– 2.86)
lnGIPC2						
lnGIPC3						
lnGIPC4						
	0.038***	– 0.014**	0.036***			
lnGIPC5	(4.63)	(– 2.52)	(4.55)			
				0.040***	– 0.010*	0.039***
lnGIPC6				(3.72)	(– 1.88)	(3.61)
lnGIPC7						
Constant						
	4.798***	4.229***	5.321***	4.751***	4.237***	5.289***
	(5.35)	(13.45)	(5.80)	(5.25)	(13.27)	(5.71)
Observations						
R-squared	3432	3432	3432	3432	3432	3432
Number of cities	0.434	0.148	0.439	0.433	0.146	0.439
City FE	286	286	286	286	286	286
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Variables	Yes	Yes	Yes	Yes	Yes	Yes
Variables	**(19) Emp**	**(20) PM2.5**	**(21) Emp**	**(22) Emp**	**(23) PM2.5**	**(24) Emp**
lnGIPC						
lnPM25						
			– 0.127***			– 0.129***
lnGIPC1			(– 2.94)			(– 2.85)
lnGIPC2						
lnGIPC3						
lnGIPC4						
lnGIPC5						
lnGIPC6						
	0.050***	– 0.006	0.049***			
lnGIPC7	(5.27)	(– 1.14)	(5.29)			
				0.027***	– 0.007*	0.026***
Constant				(4.17)	(– 1.68)	(4.05)
	4.575***	4.252***	5.114***	4.776***	4.232***	5.321***
	(5.19)	(13.26)	(5.65)	(5.30)	(13.45)	(5.75)
Observations						
R-squared	3432	3432	3432	3432	3432	3432
Number of cities	0.441	0.145	0.446	0.431	0.146	0.436
City FE	286	286	286	286	286	286
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Variables	Yes	Yes	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses

*** $p < 0.01$

** $p < 0.05$

* $p < 0.1$

reduce PM2.5 by 2% at the confidence level of 1%. This also reflects that air quality improvement is the channel through which green technology innovation affects employment.

Next, we further analyze the results from columns (4) to (24). it is found that except for alternative energy production (lnGIPC1) and administration (lnGIPC6), the other five types of green technology innovation can increase the employment level by meaningfully reducing the concentration of PM2.5 in the air. Among them, the mediating effect of air quality accounted for 4.99% of the total effect of transportation green technology innovation on employment, which was relatively the largest. It is followed by waste management at 4.57% and energy conservation at 4.36%. The proportion of mediating effect to total effect was the lowest in agricultural and forestry green technology innovation, which was 3.18%.

Table 7 (including table 7–1 to 7–4) reports the mediating effect test of industrial structure. From the coefficients in columns (1) to (3), it is known that the total effect of green technology innovation on the employment level is 0.056, while the direct effect is 0.052 (both at the 1% confidence level). Meanwhile, the mediating effect of industrial structure is remarkable, with a value of about 0.004. The coefficient of lnGIPC in column (2) indicates that green technology innovation facilitates the tilt of industrial structure to the secondary industry, which leads to a positive employment effect. Therefore, it is reasonable to believe that the progress of green technology innovation will expand the value added to the secondary industry and thus the demand for labor.

Further, columns (4) to (24) report in detail the impact of various green technology innovations on employment levels through the industrial structure. However, it is found that only transportation (lnGIPC2) and administrative management (lnGIPC6) green technologies could significantly affect the industrial structure. The industrial structure effect accounted for 7.08% and 4.63% of the total effect of transportation green technology innovation and administrative green technology innovation on employment level, respectively.

Conclusion and suggestion

This paper aims to prove that green technology innovation is a new means of balancing the relationship between environmental protection and full employment for countries around the world. Applying panel data from 286 prefecture-level cities in China from 2006 to 2017, this paper empirically examines the impact of various green technology innovations on urban employment. In order to solve the endogeneity, the instrumental variable method and dynamic panel model are employed. Meanwhile, from the perspectives of air quality and industrial structure optimization, the influence mechanism of green technology innovation on employment is deeply analyzed. This study can not only enrich the existing relevant theories on green technology innovations and employment, but also provide a new basis for explaining how green technology innovations promotes employment.

This paper mainly obtains the following conclusions. Firstly, all kinds of green technology innovations can significantly increase the level of urban employment. Among them, two types of green technology innovation, namely "administration, management or design aspects" and "alternative energy production", have the strongest employment acceleration effect. Meanwhile, the employment effect of green technology innovation is strongest in the 2nd year after the patent application is applied. Secondly, compared with non-key cities of environmental protection, the effect of green technology innovation on employment levels is stronger in key cities of environmental protection. However, green technology innovation in non-resource-based cities has a stronger employment promotion effect. Thirdly, green technology innovation can increase the livability of cities by improving their air quality, thereby attracting an influx of labor. The mediating effect of air quality is stronger for two types of green technology innovation: "transportation" and "waste management". Finally, green technology innovation induces a positive employment effect by causing the industry to tilt to the secondary industry. The mediating effect of industrial structure is more remarkable in the green technology innovation of "transportation" and "administration, management or design aspects".

Based on the above analysis and conclusion, this paper puts forward some policy suggestions for reference. Foremost, both developed and developing countries should continue to encourage the development of green technology innovation. This is not only a responsibility for the global environment and climate, but also for the sustainable development of mankind. Secondly, for those cities with an unregulated environment, the local government should pay more attention to the development of green technology innovation. Because green technology innovation brings both environmental and employment benefits. Next, resource-based cities are facing problems such as resource exhaustion and economic recession, so it is more urgent to improve the level of green technology innovation. Fourthly, given the differences in employment effects of various types of green technology innovations, priority can be given to encouraging the development of green technology innovations in the categories of "administration, management or design" and "alternative energy production". They are beneficial to solving the employment problem. Furthermore, air quality and industrial structure optimization have a

Table 7 The mediating effect of industrial structure

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Emp	**IS**	**Emp**	**Emp**	**IS**	**Emp**
lnGIPC	0.056***	0.016**	0.052***			
	(5.09)	(2.45)	(4.77)			
lnIS			0.254***			0.264***
			(3.68)			(3.78)
lnGIPC1				0.047***	0.006	0.045***
				(5.63)	(1.33)	(5.39)
lnGIPC2						
lnGIPC3						
lnGIPC4						
lnGIPC5						
lnGIPC6						
lnGIPC7						
Constant	4.738***	− 2.306***	5.323***	4.780***	− 2.288***	5.385***
	(5.35)	(− 3.98)	(5.60)	(5.39)	(− 3.97)	(5.65)
Observations	3432	3432	3432	3432	3432	3432
R-squared	0.438	0.433	0.448	0.438	0.430	0.449
Number of cities	286	286	286	286	286	286
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Variables	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
	Emp	**IS**	**Emp**	**Emp**	**IS**	**Emp**
lnGIPC						
lnIS			0.262***			0.268***
			(3.70)			(3.81)
lnGIPC1						
lnGIPC2	0.037***	0.010**	0.034***			
	(4.09)	(2.01)	(3.92)			
lnGIPC3				0.037***	0.005	0.036***
				(4.19)	(1.03)	(4.08)
lnGIPC4						
lnGIPC5						
lnGIPC6						
lnGIPC7						
Constant	4.627***	− 2.334***	5.238***	4.706***	− 2.298***	5.321***
	(5.17)	(− 3.97)	(5.43)	(5.25)	(− 3.95)	(5.52)
Observations	3432	3432	3432	3432	3432	3432
R-squared	0.433	0.431	0.444	0.433	0.430	0.445
Number of cities	286	286	286	286	286	286
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Variables	**(13)**	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**
	Emp	**IS**	**Emp**	**Emp**	**IS**	**Emp**
lnGIPC						
lnIS			0.265***			0.267***
			(3.72)			(3.70)
lnGIPC1						
lnGIPC2						

Table 7 (continued)

Variables	**(13)**	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**
	Emp	**IS**	**Emp**	**Emp**	**IS**	**Emp**
lnGIPC3						
lnGIPC4	0.038***	0.007	0.036***			
	(4.63)	(1.58)	(4.38)			
lnGIPC5				0.040***	0.006	0.038***
				(3.72)	(1.38)	(3.63)
lnGIPC6						
lnGIPC7						
Constant	4.798***	− 2.287***	5.403***	4.751***	− 2.293***	5.363***
	(5.35)	(− 3.95)	(5.60)	(5.25)	(− 3.96)	(5.49)
Observations	3432	3432	3432	3432	3432	3432
R-squared	0.434	0.430	0.445	0.433	0.430	0.445
Number of cities	286	286	286	286	286	286
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Variables	**(19)**	**(20)**	**(21)**	**(22)**	**(23)**	**(24)**
	Emp	**IS**	**Emp**	**Emp**	**IS**	**Emp**
lnGIPC						
lnIS			0.257***			0.280***
			(3.55)			(3.92)
lnGIPC1						
lnGIPC2						
lnGIPC3						
lnGIPC4						
lnGIPC5						
lnGIPC6	0.050***	0.009*	0.048***			
	(5.27)	(1.72)	(5.03)			
lnGIPC7				0.027***	− 0.005	0.028***
				(4.17)	(− 1.60)	(4.44)
Constant	4.575***	− 2.328***	5.173***	4.776***	− 2.275***	5.414***
	(5.19)	(− 3.94)	(5.42)	(5.30)	(− 3.96)	(5.60)
Observations	3432	3432	3432	3432	3432	3432
R-squared	0.441	0.431	0.452	0.431	0.430	0.443
Number of cities	286	286	286	286	286	286
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust t-statistics in parentheses

*** $p < 0.01$

** $p < 0.05$

* $p < 0.1$

significant impact on the employment level. Therefore, in addition to encouraging green and innovative development, we also need to publicize environmental protection in many ways and guide individual residents to live green life. Moreover, the green upgrading of the industrial structure also needs to be taken into account.

In fact, the conclusions of this study are not only for China but also worth learning from for developing countries. No matter emerging economies such as India, Brazil, and Turkey, which are relatively leading in development, or other less developed countries and regions, most developing countries are facing the dual pressure of promoting green economic development and stabilizing employment situation. However, this paper also has some limitations. Firstly, this paper does not conduct group discussion according to the industry and sector of employees, so it is difficult to distinguish the heterogeneous impact of green technology innovations. Secondly, the lack of timeliness of the data used in this paper is not conducive to analyzing the real situation of China's labor market in recent years. These limitations should be carefully considered in future research.

Appendix 1: Classification of Green Technology Innovation

Type	Classification of Green Technology Innovation	Detail
GPIC1	Alternative energy production	Biofuels, wind, solar, etc
GPIC2	Transportation	Hybrid electric vehicles, externally powered vehicles, etc
GPIC3	Energy conservation	Electric energy storage, low energy consumption lamps, etc
GPIC4	Waste management	Waste disposal, waste reuse, pollution control, etc
GPIC5	Agriculture or forestry	Alternative irrigation technology, pesticide substitution, soil quality improvement, etc
GPIC6	Administrative, management, or design aspects	Commuting: High Occupancy Vehicle, Telecommuting, etc.; Carbon/Emissions trading: pollution credits
GPIC7	Nuclear power generation	Nuclear engineering, gas turbine power plant using nuclear source and heat source

Appendix 2: VIF test

Variable	VIF	1/VIF
lnGIPC	2.23	0.449384
lnHC	1.55	0.64586
lnED	1.46	0.683305
lnCS	1.36	0.735754
lnPS	1.31	0.765165
lnFC	1.23	0.811269
lnIS	1.15	0.871199
Mean VIF	1.47	

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

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

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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