E3S Web of Conferences 275, 02039 (2021) https://doi.org/10.1051/e3sconf/202127502039
EILCD 2021

The impact of technological innovation on carbon emissions

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Abstract. Environmental problems caused by carbon emissions have received widespread attention, and technological innovation has an important impact on carbon emissions. This paper uses data from 30 provinces (excluding Tibet) in China from 2009 to 2018 as a sample, and empirically analyzes the relationship between technological innovation and carbon emissions by constructing panel data and fixed effects models. The results show that technological innovation can curb carbon emissions. Therefore, China should increase research and application of low-carbon technologies to promote sustainable economic development.

1 Introduction

Since the Industrial Revolution, the development of global industrialization and urbanization has led to rapid economic growth. At the same time, the economic development model at the cost of consuming a large amount of energy has brought severe challenges to the ecological environment, such as the increasing greenhouse effect. The aggravation of serious ecological problems has attracted the attention of governments of all countries. The report of the 18th National Congress of the Communist Party of China puts forward the new requirement of “substantially reducing carbon dioxide emissions” and actively carry out pilot carbon emissions trading.

The 19th National Congress of the Communist Party of China regards innovation as the first driving force for development, and requires that innovation-driven development should be adhered to, and an innovative country should be built. China’s economic construction has entered a new normal period. Technological innovation can promote the transformation and upgrading of China’s industrial structure to a certain extent, and it is an important source of driving force for high-quality economic development. The Chinese government has attached great importance to innovation activities for a long time, which will promote the vigorous development of enterprise scientific research activities, and technological innovation will play an increasingly important role.

Therefore, studying the impact of technological innovation on carbon emissions has important theoretical and practical significance for promoting China’s economic growth and reducing carbon emissions.

2 Literature review

Existing studies have explored carbon emissions and its influencing factors based on different perspectives. Studies have found that population size, industrial structure, trade opening, urbanization rate, per capita GDP, industrialization level, energy intensity, energy structure, and industrial scale all affect carbon emissions. Chen Zhanming et al.[1] (2018) found that the increase in population size and the proportion of the output value of the secondary industry will significantly increase urban carbon dioxide emissions. Xu Guoquan et al.[2] (2006) found that the contribution rate of economic development to stimulating China’s per capita carbon emissions increased exponentially, while the contribution rate of energy efficiency and energy structure to curbing China’s per capita carbon emissions showed an inverted “U” shape. Han Jing et al.[3] (2015) found that economic development, opening to the outside world, and factor endowments have a positive impact on carbon emissions performance, and the impact of energy structure and industrial structure on carbon emissions performance is unstable.

Regarding the relationship between technological innovation and carbon emissions, scholars’ research conclusions are not uniform. Some studies have found that technological innovation can curb carbon emissions: Tu Zhengge[4] (2012) analyzed the carbon emissions of China’s eight major industry sectors and believed that technological advancement promotes the decline of energy intensity and is the core driving force for carbon emission reduction. Zhang Hongwu et al.[5] (2016) selected 36 industrial industry panel data in China from 1998 to 2013 to conduct research and found that technological progress can greatly reduce industrial carbon emission. Research by other scholars has shown that technological innovation will cause an increase in carbon emissions. Jin Peizhen et al. [6] (2014) proposed

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that technological advancement in the industrial field will lead to an increase in carbon dioxide emissions as a whole. He Bin et al.[7] (2017) found that original innovation not only did not reduce carbon emissions, but increased carbon emissions, indicating that China's technological innovation pays more attention to the improvement of production capacity, and the degree of green innovation is not high. In addition, in different regions, independent innovation, imitative innovation, and technology introduction have shown great differences in the effects of carbon emission reduction.

According to the analysis of the above research status, it can be found that scholars have conducted more detailed explorations on the impact of technological innovation on carbon emissions, but the effect of technological innovation on carbon emissions is still unclear. Therefore, this paper takes 30 provinces in China as samples to analyze the impact of technological innovation on carbon emissions, in order to provide a reference for promoting low-carbon development.

3 Propose the hypothesis

There are two main mechanisms for the impact of technological innovation on carbon emissions: one is that technological innovation is a key factor in economic growth, so it will increase the demand for energy, which will increase carbon emissions; the other is that technological innovation can increase labor productivity and utilization of resources, thereby reducing carbon emissions. In addition, the development of renewable energy technologies and new energy technologies can also reduce carbon emissions. Since China adheres to the five development concepts of "innovation, coordination, green, openness, and sharing" and attaches great importance to environmental protection policies, it can be speculated that China's technological innovation should have a stronger inhibitory effect on carbon emissions than a promotion. Based on this, the hypothesis of this paper is proposed:

H1: Technological innovation has an inhibitory effect on carbon emissions.

4 Design the research

4.1. Samples and data sources

This paper selects 30 provinces across the country from 2009 to 2018 as samples, and generates a total of 300 panel data samples. The energy consumption data comes from the "China Energy Statistical Yearbook" over the years, the carbon emission index of each energy comes from the carbon emission index provided by IPCC 2006, and the total carbon emission is calculated based on the above data; the rest of the data comes from the "China Statistical Yearbook" over the years.

4.2. Model establishment

At present, the domestic research on carbon emissions mostly uses the LMDI model and the STIRPAT model. This paper adopts the extended STIRPAT model, and adds technological innovation (T), industrial structure (S), and foreign trade dependence (M) to the basic model. The basic expression form of the STIRPAT model is:

$$I=aP^bA^cT^d\varepsilon \qquad (1)$$

Among this, I represents the environmental impact caused by human activities; P represents the population, A represents the degree of affluence; T represents the level of technology; ε represents the error. The model built in this paper is:

$$C_{it}=\alpha P_{it}^{\beta 1}A_{it}^{\beta 2}T_{it}^{\beta 3}S_{it}^{\beta 4}M_{it}^{\beta 5}\varepsilon_{it} \qquad (2)$$

Among this, C is the total carbon emissions; P is the size of the population; A is the GDP per capita; T is the technological innovation; S is the industrial structure, expressed as the ratio of the secondary industry's GDP to the total value of GDP; M is the degree of foreign trade dependence, expressed as the ratio of the value of import and export trade to the total value of GDP.

Take the logarithm of both sides of the model to get the new model :

$$lnC_{it}=\alpha+\beta_1\ln P_{it}+\beta_2\ln A_{it}+\beta_3\ln T_{it}+\beta_4\ln S_{it}+\beta_5\ln M_{it}+ln\varepsilon_{it} \qquad (3)$$

Among this, α is the intercept, β_i (i=1, 2, 3, 4, 5) is the regression coefficient, and $\ln\varepsilon_{it}$ is the random disturbance term.

4.3. Definition of variables

The explanatory variable studied in this paper is the total carbon emissions, which is calculated by multiplying the seven energy sources of coal, coke, gasoline, kerosene, diesel, fuel oil and natural gas with their carbon emissions index and summing them. The types of energy and their carbon emission coefficients are shown in Table 1.

Table 1. The types and carbon emission coefficients of energy.

Type	Carbon emission coefficients (104t/104t)
coal	0.7559
coke	0.8550
gasoline	0.5538
kerosene	0.5714
diesel	0.5921
fuel oil	0.6185
natural gas	0.4483

The explanatory variable of this paper is technological innovation, which is measured by the ratio of the R&D expenditure of industrial enterprises above designated size to the total value of GDP of the region. With reference to relevant researches at home and abroad, this paper selects population size, per capita GDP, industrial structure, and foreign trade dependence as control variables. The specific information about variables is shown in Table 2.

Table 2. specific information about variables.

Symbol	Name	Calculation method
C	Total carbon emissions	The sum of the product of various energy consumption and carbon emission indicators
T	Technological innovation	The ratio of R&D expenditure of industrial enterprises above designated size to the total value of GDP
P	Population size	Number of population
A	GDP per capita	GDP per capita
S	Industrial structure	the ratio of the secondary industry's GDP to the total value of GDP
M	Foreign trade dependence	the ratio of the value of import and export trade to the total value of GDP

5 Results of Empirical Analysis

5.1. Descriptive statistics

The results of descriptive statistics are shown in Table 3. The large standard deviation of lnC indicates that China's carbon emissions vary greatly among provinces. The areas with large carbon emissions are mainly concentrated in Shanxi and Hebei; the areas with small carbon emissions are mainly distributed in Hainan and Qinghai. The standard deviation of lnM is also relatively large, indicating that different provinces have different degrees of foreign trade. The standard deviation of the remaining variables is relatively small, and the data distribution is relatively even.

Table 3. Results of descriptive statistics.

	N	mean	sd	min	P50	max
lnC	300	9.16	0.83	6.93	9.22	10.58
lnT	300	-4.81	0.61	-6.71	-4.80	-3.84
lnP	300	8.19	0.74	6.35	8.25	9.30
lnA	300	10.67	0.48	9.50	10.64	11.76
lnS	300	-0.11	0.06	-0.33	-0.10	-0.00
lnM	300	-1.84	0.98	-4.04	-2.03	0.34
lnN	300	-4.76	0.62	-6.04	-4.79	-3.56

5.2. Basic regression results

Since the sample data in this paper is panel data, considering the differences between different provinces, the problem of model setting may arise, that is, whether to choose a fixed-effect model or a random-effect model. This paper first conducts Hausman test on model (3), and the result shows that the p-value is much less than 0.05, rejecting the null hypothesis, so this paper chooses to use the fixed-effects model.

Table 4. Results of basic regression and robustness test.

	Basic regression	Robustness test	
variables	(1)	(2)	(3)
lnT	-0.0719** (0.0331)		
lnN		-0.0863* (0.0458)	
L.lnT			-0.103** (0.0500)
lnP	0.431 (0.395)	0.442 (0.396)	1.339*** (0.482)
lnA	0.238*** (0.0446)	0.237*** (0.0453)	0.0359 (0.0623)
lnM	0.0513** (0.0246)	0.0560** (0.0249)	0.108*** (0.0236)
lnS	0.277*** (0.0950)	0.296*** (0.0970)	0.0809 (0.0948)
Constant	3.059 (3.021)	2.948 (3.049)	-2.423 (3.713)
Observations	300	300	300
R-squared	0.207	0.203	0.144
Number of prov	30	30	30

The regression results are shown in Table 4, which shows that the regression coefficient of technological innovation and carbon emissions is significantly negative at the 5% significance level, indicating that China's provinces have effectively reduced carbon emissions through technological innovation. The impact may be in the following three ways: (1) Advanced production technologies and processes brought about by technological innovation can increase labor productivity and reduce energy consumption in the production process; (2) technological innovation can help improve utilization of energy, and the development and application of new energy technologies reduce people's demand for energy; (3) technological innovation can promote the transformation of economic growth from the input of material resource elements to the drive of scientific and technological knowledge elements, thereby reducing carbon emissions.

The coefficient of per capita GDP is 0.238, indicating that for every 1% increase in per capita GDP, carbon emissions will increase by 0.238%. That is, as the level of economic development increases, carbon emissions will gradually increase. This is because China is still in the industrialization stage and rapid economic development will inevitably consume a lot of energy and carbon emissions will increase significantly.

The degree of foreign trade dependence is positively related to carbon emissions, which may be due to the fact that most of the products involved in China's import and export trade are energy-dependent, which increases carbon emissions.

The increase in the proportion of the output value of the secondary industry is significantly positively correlated with the intensity of carbon emissions. This is because the main characteristics of Chinese industry are high energy consumption and high emissions, low utilization of energy, and a large amount of carbon emissions in the production process.

5.3. Robustness test

In order to determine whether the impact of technological innovation on carbon emissions is affected by the selection of variables, we conduct a robustness test on the empirical model (3). Specifically, we use the new product development funds of enterprises above the designated size to replace the R&D expenditure of industrial enterprises above designated size to conduct empirical analysis. The new empirical model can be expressed in the following form:

$$lnC_{it}=\alpha+\beta_1\ln P_{it}+\beta_2\ln A_{it}+\beta_3\ln N_{it}+\beta_4\ln S_{it}+\beta_5\ln M_{it}+ln\varepsilon_{it} \quad (4)$$

In model (4), N represents the ratio of new product development expenditure of enterprises above designated size to the total value of GDP in each region over the years, and other variables are the same as in modle (3). The regression results are shown in the third column of Table 4, which is basically consistent with the previous article.

Considering that the technological innovation in this period may have an impact on the carbon emissions in the next period, this paper applies the first-order lag processing to the “technological innovation”, and re-tests the model (3). The test results are shown in the fourth column of Table 4, The coefficient of L.lnT is negative and significant at the level of 5%, indicating that technological innovation has an inhibitory effect on carbon emissions.

6 Conclusions and recommendations

6.1. Conclusions

Based on the panel data of 30 provinces in China from 2009 to 2018, this paper establishes an extended STIRPAT model to study the relationship between the level of technological innovation and carbon emissions, and cames to the following conclusions: judging from the full sample empirical results of all provinces across the country, technological innovation has a significant effect on suppressing carbon emissions, and the current technological innovation also has a significant inhibitory effect on carbon emissions in the next period. In addition, the level of economic development, the degree of foreign trade dependence and the proportion of the output value of the secondary industry have a positive effect on carbon emissions, mainly because China is still in the process of industrialization, and the current economic development mode has a high demand for energy and a relatively low utilization rate of resources.

6.2. Recommendations

Technological innovation plays an important role in high-quality economic development. The government should increase support for enterprises to conduct research on technological innovation related to energy conservation and emission reduction, and encourage enterprises to vigorously develop low-carbon technologies.

Although the number of researchers in China is gradually increasing, there is a problem of disconnection between the research problems and the difficulties faced by the industry. Colleges and enterprises should actively establish cooperative relations to achieve the integration of production and research.

In addition, China needs to vigorously develop the tertiary industry, especially the new service industries represented by finance and insurance, high-end services, modern logistics, leisure tourism, etc., actively adjust and optimize the industrial structure, and promote the development of the industry in the direction of low-carbon and energy-saving.

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