Low Carbon Innovation and Carbon Emission Reduction: Reexamination of ICT Solow Paradox

KunQi Li, SuSu Jiang, and WeiDong Wang(✉)

School of Finance and Economics, Jiangsu University, Zhenjiang 212013, China
wangwd@ujs.edu.cn

Abstract. Technology is an important means to deal with climate change. In recent years, with the rapid development of information and communications technology (ICT), it has improved the solution of environmental problems in various regions. Based on the ICT Solow paradox, this paper analyzes 30 provinces and cities in China from 2004 to 2018, and distinguishes the eastern and western regional characteristics. The results show that the domestic regional heterogeneity is obvious, the eastern part breaks through the ICT Solow paradox limit, and ICT inhibits the emission reduction of low carbon innovation. The Midwest supports the ICT Solow Paradox, and ICT low-carbon innovation promotes emission reduction.

Keywords: Low-Carbon Technology Innovation · ICT · ICT Solow Paradox · Regional Heterogeneity

1 Introduction

After the reform and opening up, China's economy has developed rapidly and achieved remarkable results. However, in the process of modernization, China has also exposed many disadvantages such as excessive dependence on energy, unsustainable development and so on, which has become the world's largest carbon emission country. Faced with changes in the situation, the national '13th Five-Year Plan' clearly pointed out that China's nitrogen dioxide emissions per unit annual decline of 18%, and focus on the layout of cleaner production innovation. Low Carbon Transformation Requires Holistic Transformation of Technology and Production System, and Low Carbon Technology Innovation is the Key to the Transformation [8, 13]. At the same time, researchers generally regard the rapidly developing ICT (information and communications technology) as an important auxiliary means of low-carbon technological innovation [2, 7].

2 Literature Review

2.1 Low-Carbon Technology Innovation

As early as the end of last century, the problem of global warming has aroused widespread concern in various countries. The IPCC assessment report points out that the development

D. Qiu et al. (Eds.): ICBBEM 2022, AHIS 5, pp. 1547–1553, 2023.
https://doi.org/10.2991/978-94-6463-030-5_155

momentum and severity of global warming have far exceeded people's initial expectations. It has been reported that global greenhouse gas (CHG) emissions have increased by more than 70% since the 1970s [9], It is urgent to control greenhouse gas emissions and improve climate change. It can be seen that low-carbon technology innovation plays an important role in mitigating climate change, but its level and activity are different in space.

2.2 ICT Solow Paradox

Since the mid-1990s, a large number of evidence points to ICT can significantly promote productivity. Cie lik's study shows that there is a significant positive correlation between regional telecommunications infrastructure and regional economic development, indicating that ICT may have the capacity to promote economic development [6]. Visible, even if the current ICT Solow paradox temporarily disappears, but this does not deny its existence. Accordingly, some scholars have studied the reasons and proposed that the ICT Solow paradox may have stages. This stage is characterized by the threshold effect, which means that when the ICT industry reaches a certain scale, it can play a huge role in promoting productivity, but this role is not obvious before [1, 17].

Related to this, domestic scholars also put forward the problem of regional imbalance of ICT development in China. It is pointed out that since the reform and opening up, the development of China's telecommunications industry has shown a pattern of priority development in the eastern region and pulling the central and western regions, and the unbalanced regional development is obvious [11]. At present, the development of ICT is at an early stage, so it also has the same characteristics. Overall, China's regional ICT development is uneven and heterogeneous [18].

2.3 Effect of ICT on Energy Conservation and Emission Reduction

Lei Zhenzhou pointed out that ICT is a double-edged sword for climate change. The key to solving the problem of climate deterioration is to make the positive effect of ICT significantly greater than its negative effect [9, 14]. According to the in-depth study of domestic scholars on the ways of ICT assisting energy conservation and emission reduction, the main ways of its positive role are as follows: making low-carbon technological innovation technology develop faster with the help of ICT [7, 15].

In summary, due to the spatial differences of low-carbon technology innovation technology, the regional imbalance of ICT development level, the promotion of ICT on productivity may exist stages, and each region has different economic characteristics. Therefore, when studying the role of ICT in the impact of low-carbon technology innovation technology on carbon emissions, this paper conducts research at the national and regional levels, and focuses on the analysis combined with regional characteristics, making the research results more reliable.

3 Quantitative Analysis

3.1 Setting of Measurement Model

According to the literature review, a large number of studies have focused on the role and path of low-carbon technologies in mitigating climate change. Firstly, in the absence of the interaction between information technology and low-carbon technology innovation, the effects of the two on climate change mitigation are analyzed respectively, and the initial measurement model is set as shown in (1). Then, the interaction between information technology and low-carbon technology innovation is further analyzed, and the multiplication term of the two is introduced for modeling. The initial measurement model is set as shown in (2).

$$lnCarbon_{it} = \alpha_0 + \alpha_1 lnICT_{it} + \alpha_2 lninv_{it} + \beta lnX + \varepsilon_{it} \tag{1}$$

$$lnCarbon_{it} = \alpha_0 + \alpha_1 lnICT_{it} + \alpha_2 lninv_{it} + \alpha_3 lnmult_{it} + \beta lnX + \varepsilon_{it} \tag{2}$$

where, i represents each province; t represents time; Carbon for the explained variable, representing carbon emissions; ICT represent the level of information technology, the number of patent applications for relevant technology; inv represents the number of applications for low-carbon technology innovation; mult represents the interaction between low-carbon technology innovation technology and information technology; X represents a series of control variables that can affect carbon emissions; ε represents a residual item.

3.2 Data Sources and Indicators Selection

3.2.1 Data Source

This paper uses panel data of 30 provinces and cities in China (due to lack of data from Hong Kong, Macao, Taiwan and Tibet) from 2004 to 2018 as research samples. Low-carbon technology innovation is measured by the number of patents classified by Y02 in the CPC (Cooperative Patent Classification) jointly promulgated by the European Patent Office (EPO) and the United States Patent Office (USPO) in 2013. The Y02 patent classification includes six types of related technologies to alleviate climate change. The specific source of data is incopat patent database.

3.2.2 Explanated Variables

This paper aims to study the role of various selected factors in mitigating climate change, and the greenhouse gas emissions caused by energy consumption in the process of climate change play a major role. The formula is as follows.

$$Carbon_i = {}^{12}/_{44} \times \left[\sum e_{n,i} \times \alpha_n \times \beta_n\right]$$

In the formula, $Carbon_i$ refers to the carbon emissions of the first province i, the unit is ten thousand; $e_{n,j}$ refers to the terminal consumption of the first kind of energy in the

province (a total of 17 types of energy consumption are included in the analysis in this paper, including raw coal, coke, coke oven gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas, natural gas, etc.), coke oven gas, other gas and natural gas units, and their energy consumption is 10^8 m^3; α_n represents the n coal conversion coefficient of the first energy; β_n represents the carbon dioxide emission coefficient of the first energy.

3.2.3 Core Explanatory Variables

Low-carbon technology innovation (inv): The more patent applications for low-carbon technology innovation in a region, the stronger the inhibition of carbon emissions in the region. Therefore, this paper expects that the parameter symbols are negative in the national and regional analysis.

Information and communications technology (ICT): From the literature review, in the current stage of China's development, no matter in which stage of Solow paradox, information technology plays a role in promoting economic growth to a certain extent, and the process is bound to increase carbon emissions. Therefore, this paper expects that the parameter symbols are positive in the national and regional analysis.

3.2.4 Control Variables

Per capita GDP (pgdp): The higher average GDP per capita means that the region has more economic vitality, and production activities in the process of GDP output will be accompanied by higher levels of carbon emissions, so this paper expects that this can not play a catalytic role in reducing emissions.

The degree of opening to the outside world (fdi): Foreign investment can improve local environmental quality through income effect. This paper believes that the pollution heaven and pollution halo effect are different manifestations of foreign capital at different stages of entering a region [4, 12]. With the gradual development and standardization, the latter will gradually replace the former. In the current stage of our country should be more pollution paradise effect, so this paper expects this can not play a role in promoting emission reduction [3, 5, 10, 16].

Energy intensity (ei): Taking into account the regional differences in industrial structure and technical level and other factors, so the utilization rate of energy is not the same, using the ratio of energy consumption to GDP in the region, the energy needed to obtain the output per unit of GDP is expressed in coal, and the unit is tons / million yuan [2].

3.3 Measurement Model Test Results

Table 1 shows the covariance matrix of each variable. It can be seen that carbon emissions are positively correlated with ICT, low-carbon innovation technology, per capita GDP, energy efficiency and openness, which is basically in line with expectations.

Then the model is analyzed to explore the causal relationship. In order to eliminate the influence of heteroscedasticity, all variables are logarithmicized, and then the logarithmicized variables are tested by IPS single root test and cointegration test. The results show good stability.

Table 1. Variable covariance matrix.

Variable	lncarbon	lnict	lninv	lnpgdp	lnei	lnfdi
lncarbon	1					
lnict	0.6186*	1				
lninv	0.5901*	0.8602*	1			
lnpgdp	0.2992*	0.6452*	0.5575*	1		
lnei	0.1453*	0.5345*	0.2956*	0.3706*	1	
lnfdi	0.0079	0.4302*	0.2094*	0.6504*	0.5594*	1

Table 2. Measurement results of key variables.

Variable	the whole nation		eastern part		western part	
	Mod1	Mod2	Mod1	Mod2	Mod1	Mod2
lnict	0.0623*** (2.71)	0.0658*** (2.85)	0.0705 (1.28)	0.0865 (1.65)	0.0540** (2.45)	0.0409* (1.88)
lninc	−0.0599*** (−401)	−0.0548*** (−3.58)	−0.0763** (−2.56)	−0.0569* (−1.98)	−0.0393** (−2.35)	−0.0412** (−2.53)
mult		−0.00501 (−1.53)		−0.0278*** (−3.68)		0.0127*** (3.52)
lnpgdp	1.011*** (7.26)	0.922*** (6.13)	0.894*** (2.66)	0.585 (1.77)	0.869*** (5.51)	0.921*** (5.97)
Inei	0.484*** (5.84)	0.466*** (5.59)	0.445*** (2.67)	0.298* (1.82)	0.550*** (6.08)	0.603*** (6.76)
lnfdi	0.136*** (3.87)	0.146*** (4.08)	0.117 (1.60)	0.210*** (2.84)	0.132*** (3.51)	0.0955** (2.51)
cons	16.79*** (187.20)	16.91*** (50.62)	16.71*** (48.15)	16.91*** (50.62)	16.81*** (137.02)	16.74*** (138.51)
Hausman	79.55***	82.18***	66.52***	66.35***	41.25***	56.22***
Chow	121.19***	111.93***	98.12***	78.86***	118.46***	118.68***

3.4 Parameter Explanation

This paper focuses on how the development of ICT affects the effect of low carbon technology innovation on carbon emission reduction. Therefore, first of all, the role of low-carbon technology innovation and ICT in carbon emissions should be determined in Mod1 to confirm the results of previous studies. On this basis, the multiplier introduced in Mod2 is analyzed to determine the existence of ICT at the same time, the role of low-carbon technology innovation in inhibiting carbon emissions changes. Finally, a comprehensive assessment of the relationship between the three and the reasons.

Table 2 is obtained by sorting out the data results. It can be seen that all variables are satisfied with our expectations at the national and regional levels.

Information and communications technology (ICT) As shown in the table, the parameter coefficients of ICT are positive, which confirms the previous scholars' research on the existence of Solow paradox in China. On the whole, the development of ICT in China will indeed bring economic growth, but excessive production activities will increase carbon emissions and climate deterioration. This phenomenon is applicable in both the eastern and central and western regions. The purpose of low carbon technology innovation is to improve climate change and reduce greenhouse gas emissions. It can be clearly observed that low-carbon technology innovation at the national and regional levels significantly inhibits carbon emissions, which is consistent with our expectations and previous research results of a large number of scholars. The panel data at the national level show that the coefficient of the multiplication term of the two is negative, indicating that at the national level, with the development of information technology, the inhibitory effect of low-carbon technology innovation on carbon emissions will increase.

4 Conclusions

The main work of this paper is to comprehensively consider the two opposite paths of ICT on carbon emissions, empirically test the status quo of each region and provide an analytical framework based on the ICT Solow paradox. The analysis results confirm that with the development of ICT, the inhibitory effect of low-carbon technology innovation on carbon emissions has obvious heterogeneity, and also confirms the previous research. As follows:

As an important auxiliary means of low carbon technology innovation, the rapid development of ICT has realized the suppression of carbon emissions, but it cannot ignore the adverse consequences of increasing carbon emissions directly or indirectly. The main method to offset this adverse effect is to vigorously develop low-carbon technology and apply it to production, so it is necessary to carry out the overall reform of technology and production system, and low-carbon technology innovation is the key to this reform. Therefore, realizing the deep interaction and coordination between low-carbon technology innovation and ICT, making low-carbon technology innovation make better use of the help of ICT, making the carbon emission suppression effect much higher than all other possible negative effects, will be more powerful in the realization of China's emission reduction goals.

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