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Research on the Impact of Carbon Trading Policy on synergy innovation of IUR in the Context of New Quality Productivity

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Abstract: Carbon trading policy is an important driving force to promote innovation and development, and it is the key to cultivate new quality productivity for greening transformation. This paper selects the panel data of 30 provinces and cities from 2009 to 2019, and empirically examines the impact effect of carbon trading policy on synergy innovation of IUR by using a multi-temporal double-difference method. The study shows that the carbon trading policy promotes synergy innovation of IUR in the pilot regions, and the conclusion still holds after the placebo test; further research shows that the degree of technology market development level plays a mediating effect in the impact of carbon trading policy on synergy innovation of IUR, the government intervention can strengthen the positive effect of carbon trading policy on synergy innovation of IUR, and the positive promotion effect of carbon trading policy on synergy innovation of IUR in Central China is significant. The positive effect of carbon trading policy on the central region is significant, while the positive effect on the eastern and western regions is not strong.

Keywords: Carbon trading policy, Synergy innovation of IUR, Technology market, Government intervention.

1. Introduction

On January 31, 2024, General Secretary Xi Jinping emphasized at the 11th Collective Study of the Political Bureau of the 20th CPC Central Committee that "new quality productivity is the advanced productivity quality that innovation plays a dominant role, breaking away from the traditional way of economic growth and productivity development path, and has the characteristics of high-technology, high-efficiency, and high-quality, in line with the new concept of development. " This is the authoritative interpretation of the Party Central Committee on the concept of new quality productivity. With the frequent occurrence of natural disasters such as sandstorms, tornadoes, tsunamis, and droughts due to global climate change, low-carbon green development is an inevitable choice to cope with climate change and a new direction for the cultivation of new-quality productivity [1].

In 1997, the concept of carbon assets was first proposed in the Kyoto Protocol. Since then, carbon trading policies have evolved globally as it has become a new institutional arrangement to address climate change. In 2011, the National Development and Reform Commission (NDRC) approved and agreed to carry out pilot carbon emissions trading in seven provinces and cities. Carbon trading, which was piloted in 2013, has become a reality. Fujian Province became the country's 8th carbon trading pilot in December 2016, and in July 2021 officially launched a unified national carbon emissions trading market. A large number of expert studies have pointed out that the supporting role of science and technology innovation should be brought into full play in order to realize China's carbon emission reduction targets. And carbon trading builds a market mechanism that converts emissions of exhaust pollutants into assets for producers. The advantages of this mechanism can realize the responsibility of greenhouse gas emission control to enterprises, and can provide corresponding economic incentives for carbon emission reduction target, reduce the emission reduction cost of the whole society, drive the development of green science and technology innovation, and then promote the greening of industry-university-research synergistic innovation development [2].

To implement the spirit of General Secretary Xi's speech, to promote revolutionary breakthroughs in technology, in-depth transformation and upgrading of industries, and to promote the development of new productivity, we must actively drive the new engine of "scientific and technological innovation". Synergy innovation of IUR is an important mode of realizing scientific and technological innovation, which is also a new engine for promoting revolutionary breakthroughs in technology and deep transformation and upgrading of industries. Vigorously implementing the collaborative innovation between industry, academia and research will be conducive to the progress and innovation of engineering science and technology, and will vigorously promote the construction of regional innovation system, and will be able to provide a constant new impetus for the development of new productive forces.

Synergy innovation of IUR refers to the three main bodies of enterprises, universities and research and development institutions to share innovative resources and complement each other's innovative strengths, to cooperate in research and development of new scientific and technological achievements as the goal, and to form alliances to carry out research and development and innovation activities together with the criterion of benefit sharing and risk sharing. At present, the construction of regional industry-university-research cooperative innovation mechanism is facing a very difficult situation. A lot of experiences at home and abroad show that the government can play the functions of organization, leadership and service management in the process of promoting the collaborative innovation of industry-university-research institutes, and can call for all useful resources for the collaborative innovation of industry-university-research institutes [3, 4]. Carbon trading policies, on the other hand, are regulated and supervised by the government to ensure market vitality and stability. In the independent innovation of core technologies, the participation and interaction between the government and the market are the decisive factors for the success of synergy innovation of IUR projects. Therefore, in the context of vigorously cultivating new quality productivity for green transformation, it is still worth exploring whether China's carbon trading policy promotes China's synergy innovation of IUR, and there is a lack of research on its mechanism of action.

2. Literature Review

2.1. Innovation Effects of Carbon Trading Policies

At present, based on the "Porter Hypothesis" theory, some scholars have proposed that the "innovation compensation" effect resulting from environmental regulations is the key to achieving a win-win situation for economic development and environmental protection [5]. Hence, the influence of carbon trading policies on technological innovation is a subject of considerable concern for the decision-making level and the academic circle. Technological innovation generally refers to innovation aimed at creating new technologies or innovation based on scientific and technological knowledge and the resources it creates. In order to lower the cost of carbon emissions, enterprises may intensify the research and development of low-carbon technologies [2, 6, 7], develop green and low-carbon products, thereby reducing the purchase volume of carbon emission quotas or selling more carbon emission quotas to maximize the profit from emission reduction. Although low-carbon technological innovation is conducive to creating a favorable atmosphere for energy conservation and emission reduction and driving the construction of the low-carbon market to a new stage, low-carbon technological innovation confronts negative externalities such as high input costs, large capital occupation, high innovation risks, and unknown returns [3]. In the absence of government intervention, it is prone to causing problems such as insufficient impetus for enterprises to engage in low-carbon technological innovation. Simultaneously, a large number of studies have discovered that, compared with merely using means such as legal regulation policies and administrative regulation policies to mandate enterprises to increase investment related to environmental protection and pollution control, carbon emission rights trading based on market-oriented approaches has a stronger investment in low-carbon technological innovation and a more significant impact [8, 9]. Accordingly, the influence capacity of carbon emission rights trading, a market-based environmental regulation, on low-carbon technological innovation is one of the most crucial criteria for judging its success.

2.2. Carbon Trading Policy and Synergy Innovation of IUR

Synergy innovation of IUR is simply the establishment of a comprehensive partnership among industry, academia and research institutions to promote a virtuous innovation ecosystem through sharing resources and joint research and development. Among them, industry is responsible for promoting the development of new technologies and products based on market demand; academia is responsible for researching technologies and core issues; and research institutions are responsible for technology development and transformation. A large number of scholars have analyzed it in depth from multiple perspectives, such as industrial structure upgrading, university education, government intervention, and enterprise innovation quality. However, the literature on synergy innovation of IUR from the perspective of carbon trading policy is very limited. Carbon trading policy is a typical environmental regulation means to incentivize enterprises to increase the cost of scientific research and innovation inputs through market orientation, to improve the efficiency of enterprise innovation resource allocation, and to enhance the social competitiveness of enterprises. While market orientation is the premise of the development of industry-university-research synergy innovation of IUR, at the same time, industry-university-research synergy innovation of IUR is an effective way for market demand to be practiced [10]. Some scholars have proved that the demand for synergy innovation of IUR products and the competitiveness of enterprises will become the promotion factors of synergy innovation of IUR from multiple theoretical perspectives [11]. Therefore, it is worth exploring whether carbon trading policy can effectively promote the development of synergy innovation of IUR.

Since the concept of green development was put forward, building a market-oriented green technology innovation system, accelerating the development of green technology factor market, and enhancing the supporting role of science and technology in fostering new quality productivity has become an important goal of science and technology innovation work [12]. Technology market is the sum of technology commodity exchange, which covers the whole process of technology commodity research and development, commercialization and industrialization [13]. Some scholars have pointed out [14] that technology market is the external environment for innovation subjects to carry out scientific and technological innovation and diffusion, and the innovation behavior of enterprises is obviously affected by the environment of technology market, and they can obtain profits from within the technology market through interactive behavior and production activities. With this series of technology commercialization, technology transfer and other operational processes, the scale of technology market transactions and the level of development has gradually expanded. And the implementation of carbon trading policy is an important initiative to promote the development of science and technology innovation, technological progress and technology transfer [15-18]. Therefore, it is worth exploring whether the carbon trading policy can lead to the improvement of the development level of technology market. Chen Yu [19] emphasized that the level of technology market development is an indispensable link in the development of synergy innovation of IUR. Enterprises, universities and research institutes as the main body of scientific and technological innovation, the purpose of its connection is to promote the dissemination and transfer of knowledge and resources within the three, and then accelerate the commercialization and productization of scientific and technological achievements. Opening up the development level of technology market will strengthen the market orientation of scientific research and development, so that a large number of high and new technologies will flow to enterprises through the platform of technology market, which is the key to the technological progress and product renewal of enterprises, as well as accelerating the process of commercialization and industrialization of technological achievements. Therefore, the level of technology market development is likely to affect the development of the level of synergy innovation of IUR.

To date, carbon trading policy has been in place for more than 10 years and has been fully implemented nationwide. However, there is limited research on the impact and path of carbon trading policy on industry-university-research cooperative innovation. Since the opening of carbon trading policy, the activity of science and technology innovation has been increasing, and the development level of technology market has been developing and perfecting, which provides a good market environment for the development of synergy innovation of IUR. Based on this, this study will explore the mechanism path of the impact of carbon trading policy on synergy innovation of IUR from the aspect of technology market development level. Thus, it provides more theoretical and empirical support for the research of carbon trading policy and University-Industry Collaborative Innovation.

3. Materials and Methods

3.1. Model Setup

3.1.1. Double difference model

This paper adopts the multi-temporal DID method to investigate whether there is a differentiated impact of carbon trading policy implementation on synergy innovation of IUR in pilot and non-pilot regions, and regards the carbon trading pilot policy as a "quasi-natural experiment", and takes the actual year of the implementation of the carbon trading policy in each province as the time point of the policy intervention, and then divides the research subjects into the treatment and control groups, and then compares the level of synergy innovation of IUR in the two types of regions before and after the implementation of the policy. Accordingly, the research subjects are divided into treatment group and control group, and then we compare the level of University-Industry Collaborative Innovation between the two types of regions before and after the implementation of the policy, and design the model as follows:

$$Syn_{it} = \alpha_0 + \alpha_1 treat_i * policy_t + d_1 X_{it} + \beta_i + \theta_t + \varepsilon_{it} (1)$$

Where: t and i denote year and region respectively. Syn_{it}, it is the explanatory variable, which indicates the level of innovation of industry-university-research collaboration in region i in year t; The core explanatory variable $treat_i * policy_t$ is a dummy variable indicating whether region i starts to implement carbon trading policy in year t. It takes the value of 1 if and only if the province i starts to implement the carbon trading policy in year t, and takes the value of 0 in all other cases; the coefficient of this variable is the net effect of the policy to be estimated, reflecting the impact of the opening up of carbon trading policy on regional industry-university-research collaboration and innovation. X_{it} is a series of control variables, including the level of economic development, urbanization, per capita education, industrialization, etc. β_i is the province fixed effect; θ_t is the year fixed effect; ε_{it} is the random disturbance term.

3.1.2. Mediation effects model

$$M_{it} = \alpha_0 + \alpha_2 treat_i * policy_t + d_2 X_{it} + \beta_i + \theta_t + \varepsilon_{it} \quad (2)$$

3.1.3. Moderated effects model

$$Syn_{it} = \alpha_0 + \alpha_3 treat_i * policy_t * gi + d_3 X_{it} + \beta_i + \theta_t + \varepsilon_{it} (3)$$

$$Syn_{it} = \alpha_0 + \alpha_4 m_{it} * gi + d_4 X_{it} + \beta_i + \theta_t + \varepsilon_{it} \quad (4)$$

$$M_{it} = \alpha_0 + \alpha_5 treat_i * policy_t * gi + d_5 X_{it} + \beta_i + \theta_t + \varepsilon_{it} (5)$$

3.2. Variable Selection and Data Source

3.2.1. Explanatory variable

In this paper, we will refer to the practice of three scholars, including Liu Zhiying, Bai Junhong and Yuan Shengchao [21-23], to construct the coordination degree model of the synergy innovation of IUR composite system according to the theory of collaborative learning to quantitatively measure the overall level of collaborative innovation of the sub-systems of the universities, research institutes and enterprises in the region. The synergy innovation of IUR composite system is $S = \{S_j\}$, $j \in [1,4]$, S_1, S_2, S_3, S_4 represent the talent cultivation and innovation sub−system of universities, the innovation sub−system of research institutes, the research and development and application sub−system of enterprises and the collaborative interaction sub−system, respectively, and the sub−systems consist of a number of basic elements. And define $O_j = \{O_{j1}, O_{j2}, \cdots, O_{jn}\}$ as the ordinal parameter variable that determines the evolution of the industry−university−research collaborative innovation system, and j denotes the above four subsystems. For the subsystems ordinal parameter selection and weight assignment see Table 1.

In order to eliminate the influence of different scales on the data results, the mean-standard deviation method is firstly used to standardize the original data, and the following formula is used to calculate the degree of order of subsystem ordinal covariates: $s_j(o_{ji}) = \begin{cases} \frac{o_{ji}-\beta_{ji}}{\alpha_{ji}-\beta_{ji}} i \in [1, l_k] \\ \frac{\alpha_{ji}-o_{ji}}{\alpha_{ji}-\beta_{ji}} i \in [l_k+1, n] \end{cases}$

Where: $\alpha$and$\beta$are the upper and lower limits of the system order parameter, $\beta_{ji} \le o_{ji} \le \alpha_{ji}$, $i \in \{1, n\}$, $n \ge 1$, k is the subsystem order parameter critical point. Since in the actual collaborative innovation system, there will always be some o_{ji} too big or too small, and for such o_{ji}, its value interval $[\beta_{ji}, \alpha_{ji}]$ can be adjusted. $s_j(o_{ji})$ takes the value of 0 to 1, and the closer it is to 1, it means that the more this ordinal parameter component can promote the realization of the ordered structure of the subsystem.

After obtaining the ordered degree of the subsystem index, it is necessary to calculate the degree of subsystem ordering, which is obtained by linear integration of the order parameter and the weight is calculated by the CRITIC method. The calculation formula is as follows:

$$s_j(o_j) = \sum \omega_i s_j(o_{ji}),\ \omega_i \ge 0, \sum \omega_i = 1$$

ω denotes the weight value of each order parameter component. The measurement of the degree of synergy of the composite system is to re-measure the ordering degree of the system ordinal parameters from the dynamic perspective. Assuming that the ordering degree of the system ordinal parameters is $s_j^0(o_j)$ at the given initial moment, the system ordering degree of the system ordinal parameters is u_j^1 for the moment t_1 in the process of the development and evolution of the composite system, and the degree of synergy of the scientific and technological innovation and industrial upgrading in the time period of t_0~t_1 is defined as the degree of synergy of the composite system, which is calculated as follows. degree is defined as the composite system's concordance, and the calculation formula is as follows:

$$Syn_{it} = \theta \sqrt[4]{\prod_{i=1}^{n} \left| s_j^1(o_j) - s_j^0(o_j) \right|}$$

Where: $\theta = 1$ when and only when $\min[s(o_j) - s_j^0(o_j)] \geq 0$, and the larger the value of Syn_{it} is, the higher the degree of synergism of synergy innovation of IUR is.

Table 1. Synergy innovation of IUR order parameter index system and weight table

subsystem	order parameter	indicator	unit	weight
College talent training and innovation sub-system	innovation input	internal expenditure of R&D funds	ten thousand yuan	0.1686
		R&D personnel full-time equivalent	people per year	0.1385
		enrollment	per person	0.2152
	innovation output	number of R&D projects	pcs	0.1263
		number of graduates	per person	0.1991
		number of patent applications	pcs	0.1524
Research institutional innovation subsystem	innovation input	internal expenditure of R&D funds	ten thousand yuan	0.2198
		R&D personnel full-time equivalent	people per year	0.2549
	innovation output	number of R&D projects	pcs	0.3104
		number of patent applications	pcs	0.2149
Enterprise R&D and application subsystem	innovation input	internal expenditure of R&D funds	ten thousand yuan	0.2696
		R&D personnel full-time equivalent	people per year	0.2480
	innovation output	new product sales revenue	ten thousand yuan	0.1857
		number of patent applications	pcs	0.2968
Cooperative interaction subsystem	knowledge transfer and sharing	the internal R&D expenditure of universities comes from the funds of enterprises	ten thousand yuan	0.2028
		the internal expenditure of R&D funds of research institutions comes from the funds of enterprises	ten thousand yuan	0.2604
		total amount of technology transfer contracts signed between universities and enterprises	ten thousand yuan	0.2921
		number of scientific and technological papers of different units in the same province	pcs	0.2446

3.2.2. Explanatory variable

Carbon-trading pilot policy ($treat_i * policy_t$). the interaction term $treat_i * policy_t$ represents the dummy variable that indicates whether the region i starts the implementation of the carbon-trading policy in the year t, and the value of the dummy variable that indicates whether the region i starts the implementation of the carbon-trading policy in the year t, If region i starts to implement carbon-trading policy in year t, then $treat_i * policy_t$ takes 1, otherwise it takes 0, and its coefficient reflects the impact of the implementation of carbon-trading policy on the decarbonization of regional energy consumption structure. The carbon-trading policy was implemented in eight provinces and cities, namely Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, Shenzhen and Fujian, from 2013 to 2016, among which Shenzhen belongs to Guangdong Province. Therefore, the treatment group of this paper is Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Fujian, and the remaining provinces are included in the control group.

3.2.3. Mediating variables

Technology market technology contracts reflect the economic and social situation for the introduction and utilization of technology, which is an important way for science and technology to promote the economy [24]. Therefore, the degree of technology market development level (M), the use of regional technology contract turnover (billion yuan) to take the logarithm to measure.

3.2.4. Moderator variable

In the context of greening transformation of new quality productivity cultivation, the government occupies an important position in the innovative allocation of production factors and resources. Government intervention is one of the most common means to compensate for market failure and enterprise technology resource allocation failure [25]. On the one hand, the government can give enterprises in science and technology innovation subsidies and tax incentives, so as to increase the enterprise retained funds; on the other hand, the government directly give enterprises financial subsidies, increase the operating costs of enterprises, expand the innovation capital investment, stimulate the enterprise technological innovation motivation [26]. However, due to the variability of the socio-economic environment in each region, it will lead to different degrees of government intervention, which in turn will have different effects on the development of synergy innovation of IUR. Domestic scholars Bai Junhong and Bian Yuanchao [21, 27] believe that government support significantly promotes Synergy innovation of IUR, and government financial support and policy guidance can alleviate the "market failure" triggered by the spillover of University-Industry-Research Knowledge Production, but government intervention is excessive and government funds on the enterprise funds "extrusion" will also have a negative impact on the Synergy innovation of IUR development. However, excessive government intervention and the "crowding out" of government funds to enterprise funds will also have some negative impacts on the collaborative innovation of industry-university-research; Chen Huaichao [28] and other researchers found that both formal and informal institutional support will have a positive impact on the collaborative innovation of industry-university-research. Based on this, this paper finds it worthwhile to explore the moderating effect of the degree of government intervention on carbon trading policy and synergy innovation of IUR. Therefore, in the data analysis, the degree of government intervention (GC) is set to be characterized by taking the logarithm of government expenditure on science and technology.

3.2.5. Control variable

The industrialization level (INL) is set using the share of industrial added value in regional GDP. The level of external development (O) is measured by the amount of investment by foreign-invested enterprises in the region, which is converted into RMB using the exchange rate of the current year, and is characterized by its share of regional GDP. The level of economic development (GDP), expressed in logarithmic terms as per capita GDP at constant 2008 prices. The level of urbanization (U) for both regional urban population as a share of total population. For the level of regional human capital (H), the accounting indicator used in this paper is the average years of education of the regional population. As shown in Table 2.

Table 2. Names of main variables and their calculation methods

variable	symbol	computing method
Synergy innovation of IUR	SYNit	construction of comprehensive index
Technology market development level	M	Logarithm of regional technical contract turnover
Government intervention	GI	Take logarithm of government expenditure on science and technology
Level of industrialization	INL	industrial added value as a share of gross regional product
Opening	O	the proportion of the investment of foreign-invested enterprises converted into RMB in the gross regional product
Economic development level	GDP	take the logarithm of GDP per capita at constant 2008 prices
Urbanization	U	urban population as a percentage of the population
Human resource level	H	Per capita years of schooling

3.3. Data Availability

Due to the serious lack of data in Tibet and Hong Kong, Macao and Taiwan, this paper selects the panel data of 30 provinces (municipalities and autonomous regions) in China from 2009 to 2019 for analysis, and the other data of the original data of each variable come from the statistical yearbooks of each region and the China Statistical Yearbook in all the previous years, and the relevant data in the indicators of the measurement of synergy innovation of IUR come from the corresponding years of the China Science and Technology Statistics Yearbook, as well as China Regional Innovation Capability Report and Compendium of Science and Technology Statistics of Higher Education Institutions in previous years.

4. Results

4.1. Benchmark Regression

Table 3. Benchmark regression results

	(1) syn	(2) syn	(3) syn	(4) syn	(5) syn	(6) syn
policytreat	0.7811***	0.7789***	0.7774***	0.7688***	0.7993***	0.7940***
	(0.1514)	(0.1517)	(0.1547)	(0.1549)	(0.1623)	(0.1604)
gdp		-0.1864	-0.1879	-0.0517	-0.2219	-0.5899
		(0.4418)	(0.4434)	(0.4648)	(0.5367)	(0.5466)
o			-0.0033	-0.0005	-0.0058	-0.0117
			(0.0614)	(0.0614)	(0.0621)	(0.0614)
u				-0.1581	-0.1748	-0.1310
				(0.1617)	(0.1639)	(0.1628)
h					-0.0683	-0.0878
					(0.1073)	(0.1063)
inl						0.3507***
						(0.1258)
_cons	1.0114***	1.1824**	1.1904**	1.3840***	1.6756***	2.0804***
	(0.2250)	(0.4636)	(0.4876)	(0.5262)	(0.6983)	(0.7053)
N	330	330	330	330	330	330
R^2	0.6731	0.6733	0.6733	0.6744	0.6748	0.6835
adj. R^2	0.6278	0.6268	0.6255	0.6254	0.6246	0.6334

Note: Standard errors are in parentheses; ∗∗∗ denotes p < 0.01, ∗∗∗ denotes p < 0.05, and ∗∗ denotes p < 0.1. Same below.

This paper adopts multi-temporal multiple difference method-DID model to test the impact of carbon trading policy on synergy innovation of IUR in the pilot region, and the results are shown in Table 3. Column (1) is only the direct effect of carbon trading policy on synergy innovation of IUR, and columns (2)-(6) are the results of adding control variables in turn, and it can be found that the core explanations of carbon trading policy on synergy innovation of IUR in the pilot region are not significant at the 1% level. The regression coefficients of the interaction term ($treat_i * policy_t$) are significantly positive at 1% level, which indicates that the empirical test of this paper is robust. The results of the benchmark regression show that the openness of carbon trading policy effectively and positively promotes regional synergy innovation of IUR, and the hypothesis is initially verified.

4.2. Parallel Trend Tests

The above baseline regression results analyze the average effect of carbon trading policy openness on the impact of synergy innovation of IUR in each region over a period of time. In order to ensure the rigor of the research results, this study introduces the parallel trend test to further analyze the dynamic impact of the carbon trading policy on synergy innovation of IUR.

The results of the parallel trend test are shown in Figure 1. The confidence intervals of the interaction term coefficients from 4 years before the opening of the carbon trading policy to the current year contain 0, and the coefficients are not significant, which indicates that the treatment group and the control group have the same trend of becoming before the opening of the carbon trading policy, and there is no significant difference. Two years after the implementation of the carbon trading policy, the confidence intervals of the interaction term coefficients do not contain 0, and the regression coefficients of the group are enhanced year by year, which indicates that the opening of the carbon trading policy has a facilitating effect on the synergy innovation of IUR and is strengthened year by year. The reason why the coefficient of the interaction term is not significant in the year of policy implementation and the next two years may be because the pilot provinces only made adjustments to the development of synergy innovation of IUR after receiving the Notice on Carbon Emission Trading Pilot Work issued by the National Development and Reform Commission, but the delayed effect occurs because of the time cycle of technological innovation and research and development.

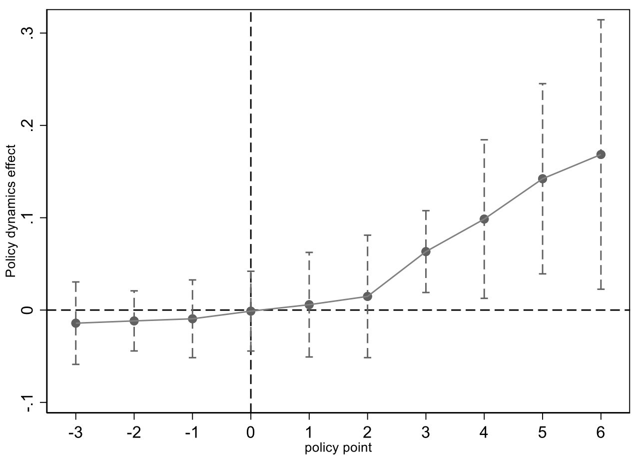

Figure 1. Parallel trend test

4.3. Placebo Test

In order to exclude that the changes of University-Industry Collaboration and Innovation in the treatment and control groups are influenced by other unknown factors or other policies, a placebo test with a number of randomized dummy experimental groups in all samples is applied. Specifically, 8 provinces and municipalities are randomly selected from 30 provinces and municipalities as "pseudo-treatment group", then generate "pseudo-policy dummy variables", the remaining provinces and municipalities as the control group, and at the same time, randomly generate the time of the dummy policy, and then carry out regression analysis. The randomization process is repeated 500 times, and the corresponding regression coefficients of the interaction term ($treat_i * policy_t$) between the dummy treatment group and the dummy policy time are obtained, and their distributions are shown in Figure 2.

In Figure 2, the regression coefficients of the virtual treatment group and the virtual policy time interaction term ($treat_i * policy_t$) are basically clustered around 0, which deviates from the actual regression coefficients obtained in the baseline regression; and most of the estimates have p-values larger than 0.01 (insignificant at 10% level), which suggests that our estimations are unlikely to be obtained by chance, and thus indicates that the effect of actual carbon trading policy liberalization on regional synergy innovation of IUR is unlikely to have been influenced by other policies or stochastic factors. The placebo test results corroborate the robustness of the benchmark regression results.

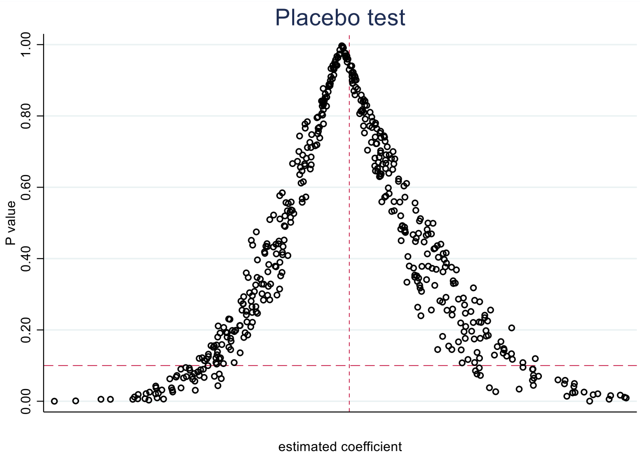

Figure 2. Placebo test

5. Mechanism Analysis

5.1. Mediation Effect Test

The regression results of the mediated effect test are shown in Table 4. Among them, columns (1) and (2) test the direct effect of the implementation of carbon trading policy on the level of synergy innovation of IUR and technology market development, respectively, and column (3) is to test the mediating effect of the level of technology market development in the impact of carbon trading policy on the synergy innovation of IUR.

In column (1) of Table 4, the regression coefficient of the interaction term of the core explanatory variable ($treat_i * policy_t$) in column (3) is 0.4022, and the coefficients of the two variables change significantly, and the regression coefficient of the interaction term of the core explanatory variable in column (2) is 0.5011. The regression coefficient of the interaction term of the core explanatory variable in column (2) ($treat_i * policy_t$) is 0.5011, and both of them are statistically significant at 1% level, which indicates that the opening up of the carbon trading policy has a positive effect on the development of the level of technology market development, which in turn improves the collaborative innovation among the industry-university-research institutes of the pilot region.

Table 4. Mediating effects regression results

	(1) syn	(2) m	(3) syn
policytreat	0.7940***	0.5011***	0.4022***
	(0.1604)	(0.0931)	(0.1503)
gdp	-0.5899	-1.2441***	0.3828
	(0.5466)	(0.3172)	(0.5011)
o	-0.0117	-0.1007***	0.0670
	(0.0614)	(0.0356)	(0.0556)
u	-0.1310	0.0628	-0.1801
	(0.1628)	(0.0944)	(0.1454)
h	-0.0878	0.2395***	-0.2751***
	(0.1063)	(0.0617)	(0.0974)
inl	0.3507***	0.3561***	0.0722
	(0.1258)	(0.0730)	(0.1169)
m			0.7819***
			(0.0913)
_cons	2.0804***	1.0106**	1.2902**
	(0.7053)	(0.4092)	(0.6364)
N	330	330	330
R^2	0.6835	0.8935	0.7486
adj. R^2	0.6334	0.8766	0.7078

5.2. Test of Moderating Effects - Government Intervention

In fact, since the carbon trading policy has been expanded since its launch in 2013, it is of great practical significance to explore how the degree of intervention by provincial and municipal governments affects synergy innovation of IUR.

The regression results are shown in Table 5. Among them, column (1) is to test the moderating effect of the degree of government intervention on carbon trading policy and University-Industry Collaborative Innovation, column (2) is to test the moderating effect of the degree of government intervention between the carbon trading policy and the level of technology market development, and column (3) is to explore the moderating effect of the degree of government intervention between the level of technology market development and University-Industry Collaborative Innovation. As can be seen from the regression results in Table 5, the regression coefficients of the core explanatory variables polxgi ($treat_i * policy_t * gi$) and mxgi ($m * gi$) of the moderated model are both significant at 1% significance level, and their regression coefficients are positive when the arbitrary moderating mechanism is tested. Therefore, the test results indicate that the degree of government intervention has a positive impact on the collaborative innovation of industry-university-research in the pilot region, and also promotes the development level of the technology market in the region, which in turn promotes the development of green and low-carbon new quality productivity.

Table 5. Moderated effects regression results

	(1)	(2)	(3)
	syn	m	syn
polxgi	1.0905***	0.7119***	
	(0.1442)	(0.0821)	
o	0.0527	-0.8316***	1.1093**
	(0.5178)	(0.2950)	(0.4996)
u	0.0477	-0.0611*	0.0753
	(0.0593)	(0.0338)	(0.0554)
h	-0.0982	0.0843	-0.1338
	(0.1548)	(0.0882)	(0.1444)
inl	-0.1176	0.2167***	-0.1807*
	(0.0996)	(0.0567)	(0.0933)
mxgi			0.4670***
			(0.0450)
_cons	1.0385	0.3319	0.5220
	(0.6828)	(0.3889)	(0.6421)
N	330	330	330
R^2	0.7139	0.9072	0.7507
adj. R^2	0.6685	0.8924	0.7112

6. Tests for Regional Heterogeneity

Although the carbon trading policy has a positive effect on synergy innovation of IUR in the national sample, the social resource endowment of each region in China varies, and the management efficiency of each local government is also different, so there is likely to be regional heterogeneity in the effect of the carbon trading policy on synergy innovation of IUR. For this reason, the sample provinces will be divided into eastern, central and western segments for regression based on the National Bureau of Statistics division standard. As shown in Table 6, the positive driving effect of carbon trading policy is mainly reflected in the central region, and the regression coefficient of the interaction term of the core explanatory variables ($treat_i * policy_t$) is 0.4751, which is significant at the 1% level. Carbon trading policy also has a certain promotion effect on the development level of synergy innovation of IUR in the western region, and the regression coefficient of the interaction term of the core explanatory variables ($treat_i * policy_t$) is 0.2793, but the effect of carbon trading policy on the western region is not as good as that in the eastern region. The reason may be due to the eastern region's superior geographic location, high cultural value of laborers, developed economy, high-tech industry incubator, the level of scientific and technological development has been far ahead of the central and western regions, and its industrial structure, economic structure is perfect, for the implementation of the carbon trading policy to provide a good economic environment and institutional basis, but the policy on the eastern part of the synergy innovation of IUR level of the development of the role of the enhancement of the level of near-saturation, that is, in the existing However, the policy is close to saturation for the enhancement of the development level of synergy innovation of IUR in the east, i.e., it is close to the optimal condition under the existing constraints of science and technology innovation and policy conditions. Compared with the central and eastern regions, the western region has the contradictions of weakening of innovation and development momentum, low level of industrial structure, and the momentum of economic modernization construction has not yet been transformed. Moreover, there are problems of insufficient education supply and low education capacity in education development, which is mainly due to the friction constraints in the integration of industry, academia and research, as its educational advantages have not yet been transformed into R&D and technological advantages.

Therefore, although the carbon trading policy can significantly promote the development of regional synergy innovation of IUR from the overall view of the whole country, there are still differences in the subregion. Therefore, when promoting the carbon trading policy for the whole country, we should adapt to the local conditions, formulate the implementation system in line with the conditions of the local economy, humanities and educational environment, and reasonably allocate the carbon quotas, so as to achieve the highest efficiency of the development of synergy innovation of IUR and make steady progress towards the green and low-carbonization society. Steady progress towards a green and low-carbon society.

Table 6. Regional heterogeneity regression results

	(1)	(2)	(3)	(4)
	syn	east	middle	west
policytreat	0.7021***	0.0963	0.4751**	0.2793
	(0.1748)	(0.3927)	(0.1826)	(0.2938)
gdp2	-0.4840	-1.8876	2.8469***	1.1432
	(0.5529)	(1.3798)	(0.6126)	(1.0101)
o	-0.0174	-0.0817	1.8586**	-0.4432
	(0.0623)	(0.0937)	(0.7714)	(0.5439)
u	-0.1129	-1.9297**	-0.0697	0.2460
	(0.1651)	(0.7701)	(0.1142)	(0.2151)
h	-0.0718	-0.3915	-0.0316	0.1375
	(0.1086)	(0.2431)	(0.1993)	(0.1357)
inl	0.3206**	1.1158**	-0.1355	-0.0650
	(0.1278)	(0.4251)	(0.1028)	(0.1557)
_cons	1.9588***	8.0714***	3.7878***	1.7178
	(0.7151)	(2.2684)	(0.8079)	(1.3309)
N	330	121	88	110
R^2	0.6747	0.6950	0.8755	0.7749
adj. R^2	0.6231	0.6107	0.8308	0.7079

7. Conclusion and Recommendation

This paper explores the influence role and mechanism path by establishing a multi-temporal DID double difference model of carbon trading policy and regional synergy innovation of IUR. The main conclusions are as follows: the carbon trading policy promotes the collaborative innovation of industry-university-research in the pilot region; the carbon trading policy is promoted by the central and local governments, and the investment in technological research and development, control and so on will be greatly increased, and its implementation has a positive impact on the collaborative innovation of industry-university-research, and the development level of the technological market plays an intermediary effect in the impact of the carbon trading policy on the collaborative innovation of industry-university-research; and the change of the degree of the intervention of the regional government Changes in the level of regional government intervention will also play a moderating effect in the impact of policy implementation on industry-university-research cooperative innovation; due to the existence of large differences in sub-regional resource factors, education levels, etc., although the carbon trading policy has a positive impact on the eastern, central and western regions, the effect of the central region is stronger than that of the eastern and western regions.

Therefore, we put forward the following suggestions: (1) In the process of promoting the implementation of the comprehensive carbon trading policy, the central and local governments should strengthen the supervision of enterprises on the implementation of the policy, and the local governments should actively participate in the construction of the synergy innovation of IUR system, to ensure the rational allocation of resources, the construction of a perfect system, as well as to ensure the implementation of the construction of the carriers of the synergy innovation of IUR, and to broaden the source of funding for the platform of collaborative innovation and the channel for the transfer of science and technology. transfer channels. (2) Give full play to the vitality of the main body of the carbon trading policy, prompting the significant expansion of the scale of China's carbon trading policy, the continuous optimization of the market structure, and the increasing perfection of the market trading environment, the huge potential of the market can stimulate a new round of investment in green assets, which is the key to promoting the synergistic innovation of industry-university-research institutes. (3) The central and local governments should vigorously support the green technology development and low-carbon product manufacturing of universities, enterprises and scientific research institutions, and actively guide enterprises to carry out scientific and technological innovation and research and development, so as to promote the development of the green economy in the region. Vigorously develop education and cultivate scientific and technological talents, while not forgetting to promote the integration of industry, academia and research to improve the overall innovation capacity. (4) China's regional economic and geographic differences are large, to promote the development of industry-university-research collaboration and innovation in different regions, according to local conditions. In particular, to strengthen the effectiveness of the implementation of carbon trading policy in the western region, the central and eastern regions can play a leading role in demonstrating the implementation of carbon trading policy experience, providing high-tech green technical support, continue to optimize the regional economic development environment, and accelerate the construction of regional infrastructure support.

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Declarations

The authors report there are no competing interests to declare.

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