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Innovation suppression and migration effect: The unintentional consequences of environmental regulation

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ABSTRACT

Carbon emissions and trading system as an effective means of mitigating greenhouse gas emissions, has been implemented in Europe and has received strong academic attention, but this paper focuses on whether China's Carbon Emissions and Trading Pilot (CCETP) will have an impact on enterprise innovation. In the course of the study, this policy provides us with a "quasi-natural experiment". This paper focuses on the causal effect of the environmental regulation of CCETP on the Chinese enterprises innovation, and according to difference-in-differences (DID) and difference-in-difference-in-differences (DDD) methods, it is found that CCETP will significantly reduce the enterprise innovation, in the meantime, this causal mechanism has a migration effect which means this inhibitory effect is not only effective for regulated enterprises, but also has a significant impact on non-regulated enterprises and other enterprises in the local region, especially on high pollution and stated-owned enterprises and the results are still valid after a series of robustness tests. In the meantime, we have explored the mechanism of this effect. This paper provides a new reference perspective for the formulation of environmental regulation policies.

1. Introduction

With the continuous expansion of human activities, climate change and environmental conditions are also deeply affected, which become one of the vital problems that need to be paid attention to and solved. Faced with mass greenhouse gas emissions and the increasingly obvious trend of global warming, many countries and regions in the world actively put forward countermeasures, and environmental regulation has become one of the indispensable means. Facing the uncontrolled emission of greenhouse gas of which carbon dioxide is the main factor, carbon emissions and trading controls have become an important measure and good choice to control climate change and reduce carbon emissions for most countries and regions. To this end, the EU has put forward the famous "The EU Emissions Trading System" (EU ETS) in order to realize the environmental regulation on the enterprises which carry out carbon emissions. Through the implementation of pricing enterprise pollution behavior, the system requires all enterprises to carry out emissions by means of purchasing carbon emissions quotas, which has drawn much attention and made some important effects in some way.

Since the reform and opening up, with the steady rise of economic and social development, climate change and greenhouse gas

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emissions and other environmental problems have become the high priority among the people of China and the world. Up to now, China has become the largest total carbon emissions country in the world. According to the data of International Energy Agency, China's carbon dioxide emissions from the combustion of fossil energy reached 6.509 billion tons in 2008 and the United States was 5.595 billion tons, which means China is 9 billion tons more than the United States and one third higher than the total emissions of the 27 EU countries, also accounts for 22% of total global emissions. Therefore, China is facing the problem of greenhouse gas emissions which need to be eased immediately. Hence, Chinese government officially announced the first clear and quantifiable target of controlling greenhouse gas emissions in 2009, which is the unit GDP carbon emissions in 2020 40%–45% less than in 2005. For this goal, the specific measure is the establishment of China Carbon Emissions and Trading Pilot (CCETP) policy nationwide, which is similar to the functions of EU ETS that using pricing strategy on the enterprise carbon emissions to reduce the total carbon emissions by increasing the cost of polluting behavior. Since the launch of EU ETS, it has aroused wide attention and academic research by scholars. Much literature shows that the system's policy effect is very significant, also influences the behavior of enterprises. Therefore, compared with the outstanding policy effect of EU ETS, how about the policy effect of CCETP?

The success of an environmental regulation mainly depends on whether it reduces the enterprise emission level. However, whether the policy affects innovation is also one of the important signs of success (Kneese & Schultze, 1975; Pizer & Popp, 2008). Since John Hicks (1932) firstly proposes the "innovation hypothesis", Porter (1991), and Porter and Van der Linde (1995) also introduce the enterprise innovation into the field of environmental policy for the first time. They believe that good and effective environmental regulation not only benefits the environment itself, but also affects the enterprises positively, which is known as the "Porter Hypothesis" that means when the enterprise is faced with imperfect competition such as incomplete information, environmental regulation can improve the development level of technological innovation to offset the opportunity cost of the enterprise brought into the market. Since the 1990s, the hypothesis has a strong response, and many related empirical analyses are carried out by a lot of literature (Rubashkina, 2013). Some scholars use data of Japan and Germany for the first analysis of the relationship between patent and environmental regulation (Lanjouw and Mody, 1996). Jaffe and Palmer (1997) finds that environmental regulation of the United States can significantly improve the enterprise's R&D activities from 1973 to 1991. Meanwhile, other scholars from Japan, Canada, Taiwan, OECD and other countries or regions also discuss and analyze their relationship (Brunnermeier and Cohen, 2003; Gray and Shadbegian, 1995, 2003; de Vries and Withagen, 2005; Hamamoto, 2006; Lanoie, Patry, and Lajeunesse, 2008; Carrión-Flores and Innes, 2010; Johnstone, Haščič, and Popp, 2010; Yang, Tseng, and Chen, 2012). Therefore, as one of the typical environmental policies, can carbon emissions and trading policy affect the level of enterprise innovation? EU ETS is regarded as the world's largest carbon market trading pilot (Calel and Dechezlepretre, 2016) and how about its policy effect? According to the theory and views, many scholars cannot agree on which is right, so their studies have a further detailed discussion. Jaffe et al. (1999, 2005), Stavins (2007) and European Commission (2005) find that the establishment of the carbon market has a stimulating effect on the enterprise technology reform. At the same time, some scholars also believe that EU ETS can directly affect the enterprise innovation and improve the energy saving technology (Hoffmann, 2007; Rogge and Hoffmann, 2010; Rogge, Schleich, Haussmann, Roser, and Reitze, 2011). Anderson and Di Maria (2011) finds that EU ETS can improve the development of the enterprise clean technology in some way. Rubashkina, Galeotti, and Verdolini (2015) believes that this incentive mechanism can significantly improve the enterprise innovation ability through the analysis of the European manufacturing department. Calel and Dechezlepretre (2016) analyzes the direct effect of EU ETS on enterprise innovation, the results show that EU ETS can significantly increase the number of enterprise patent. The study of Martin, Muûls, De Preux, and Wagner (2014a) claims that the enterprise of the EU which is lower than the quota, whose innovation ability will be more regulated by the environmental policy. Through the study of innovative data from the 1000 Italian companies, Borghesi et al. (2012) finds that those who are not subject to strict regulation of the quota policy have a stronger technological innovation ability. But on the other hand, due to the availability restriction of enterprise innovation data, a large number of empirical studies are carried out from the angle of case analysis, which is not representative (Martin, Muûls, de Preux, and Wagner, 2014b). Therefore, it is possible that the results will be inconsistencies among different researches. Contrary to the above empirical results, many scholars find that since the establishment of the EU ETS, the limitation of emission right has been significantly damaged the enterprise innovation activity (Schleich and Betz, 2005; Gagelmann and Frondel, 2005; Grubb et al., 2005). Löfgren, Wråke, Hagberg, and Roth (2013) surveys the Swedish from 2002 to 2008 and there is no evidence shows that environmental policy will have an impact on enterprise behavior. Through the investigation of 36 German companies in 2008 and 2009, Rogge, Schneider, and Hoffmann (2011) finds that only one fifth of enterprises believe that the policy can change their own enterprise innovation behavior, but no one believes that innovation can be changed by the policy in a short term. In addition, Pontoglio (2008) researches the local enterprises by case study and finds that they do not care about the innovation of enterprise technology under the regulation policy. And Walker et al. (2009) considers that environmental regulation will not have an impact on the enterprise technical level by the Irish business survey.

Therefore, four points can be drawn from the above literature analysis. Firstly, EU ETS policy will have an impact on enterprise innovative behavior in some way, but the assessment of this policy effect should be discussed and considered. Secondly, at the same time, in the empirical process of the relevant literature, some cases cannot prove the causal relationship between them, so there will be some defects in the identification of cause and effect. Thirdly, due to the availability restriction of the enterprise innovative data, many effect assessments of environmental regulations and policies are carried out by the way of evidence obtaining and case investigation, which does not have rigorous data mining and empirical analysis so that estimated results may have deviation. Hence the effect assessment of EU ETS has the opposite conclusion. Fourthly, in the research and analysis of carbon emissions policy, most literature's object is the impact of the EU ETS on enterprise innovation, and they pay less attention to the world's second largest carbon emissions trading market and the policy effect of CCETP.

Hence, by aiming at the improvement of the above points, we will have a certain degree of innovation. Firstly, we obtain the micro data of the enterprise level and takes the "the number of enterprise patent" as a proxy for "innovation" according to previous literature (Popp, 2006; Johnstone et al. 2010; Aghion, Dechezleprêtre, Hemous, Martin, and Van Reenen, 2016; Moser and Voena, 2012), because few significant technological progress and innovation is not in form of patent for protection. Secondly, in order to accurately identify the causal effect between them and eliminate endogeneity, we will use the same method by previous researches (List, Millimet, Fredriksson, and McHone, 2003; Greenstone and Gayer, 2009) that constructing the quasi-natural experiment on environmental policy, which makes CCETP policy as the research object to analyze enterprise innovation. Thirdly, we analyze the problem through the quasi-natural experiments from the perspective of empirical experience, and uses the difference-in-differences (DID), difference-in-difference-in-differences (DDD), instrumental variables (IV) and other measures to take further test for the results in order to ensure the reliability of the results. Fourthly, the research object will be CCETP in order to discuss whether the effect of the environmental regulation is diverse in different countries.

The structure of the remaining paper is organized as follows: Section 2 introduces the background of CCETP in detail. Section 3 illustrates the identification strategy, model construction and data sources. Section 4 shows the empirical conclusions, which mainly analyze the impact of CCETP on enterprise innovation and consider the migration effect. Section 5 describes robustness tests for the main conclusions. Section 6 mainly discusses the influence mechanism of CCETP on enterprise innovation. Finally, Section 7 concludes.

2. Background of CCETP policy

Since the beginning of 1970s, the U.S. Environmental Protection Agency and some states set up plans about pollutant emissions for a start of global pollutant emissions trading system. And since the signing of the "Kyoto Protocol", the carbon emissions trading policy has become the important means to control greenhouse gas emissions and improve the utilization efficiency of energy in many countries and regions around the world. So far, the region which have already established the perfect carbon emissions trading mechanism is the European Union. As the world's largest carbon emissions country, China's control of total carbon emissions and the implementation of carbon emissions and trading system are in urgent.

Aiming at the grim trend of Chinese carbon emissions, the State Council issued the "12th Five-Year work plan for controlling greenhouse gas emissions" in 2011. And in the same year, the National Development and Reform Commission formally issued the "notice on carrying out the trading pilot of carbon emissions", which marks the formal establishment of CCETP. And Beijing City, Tianjin City, Shanghai City, Chongqing City, Hubei Province, Guangdong Province and Shenzhen City were allowed to carry out carbon emissions trading pilot. So far, all seven pilot provinces or cities have already carried out the carbon emissions trading, as

Fig. 1. CCETP distribution.

shown in Fig. 1.

By the end of 2015, the cumulative volume of pilot secondary market quota in seven carbon trading markets in China reached 50.32 million tons, or 1.413 billion RMB, the average transaction price is 28 yuan per ton. CCER cumulative volume is 35.60 million tons, around 300 million RMB, and the average transaction price is around 8 yuan per ton. The size of transactions is relatively big in Hubei, Guangdong, Shenzhen and Beijing, with a higher level of market activity. It is worth noting that, to exploring the price transmission mechanism between the primary and secondary markets and a reasonable pricing mechanism, some pilot carbon trades in Guangdong introduced auction system besides free quota allocation.

Moreover, the establishment and running of carbon trading market promoted the development of carbon financial business, diversified the methods of financing for emission-reduction, and further satisfied the diversification demand from carbon market participants. Each district enhanced supervision and law enforcement of fulfillment during the process of developing pilot markets. In 2014 and 2015, the agreement fulfillment rate reached 96% and 98% separately. By exploring from pilot districts, a binding transaction and policy system which covers part of economic departments has almost formed.

Since 2013, the seven pilots completed 2-year or 3-year agreement fulfillment tasks successively. According to the recent released report, by December 31, 2016, the accumulative volume in the pilot carbon markets is 100 million tons, or 2.5 billion yuan. The market is larger and more active than before. The secondary markets, including Fujian, the total carbon quota transaction from online and offline business is around 64 million tons, increased by 80% approximately compared to 2015; the turnover is 1.04 billion yuan, which increased by 22.1% compared to last year.

In 2016, National Development and Reform Commission released a report, said China should make unified plan for national carbon market, and requested the initialization of nationwide carbon market in 2017. After the release of unified carbon emission right transaction market in this year, 7000–8000 companies from eight different areas are expected to be poured into the carbon trading market, and then a market covering 3–4 billion tons carbon quota will be established. At that time, China will become the largest carbon trading market in the world. The total amount and market share of carbon credits for each pilot are shown in Table 1.

In February 17, 2016, UNDP released a report in Beijing, said with the processing of CCETP, carbon finance will play an important role in controlling the emission of greenhouse gases and promoting energy transmission. The CCETP in China will cover 4 billion tons of carbon dioxide, more than twice as carbon market in Europe. “China's national carbon limit trading plan, which aims to limit greenhouse gas emissions, could be introduced later in 2017” is one of the most worth looking forward scientific events in 2017 by the assessment of Nature.

3. Model and data

Through the background of CCETP, we can see that the decision made by the Chinese government to make carbon trading is not only an effect on China's response to climate change and improving the quality of the environment, but it also has a positive effect on establishment of a unified global carbon market. However, it is surprising that the existing research focuses only on the comparative study of the distribution of carbon rights in the CCETP. Most of the literature is simply a descriptive introduction, and there is no rigorous measurement test, in the meantime, the effectiveness of the policy evaluation is rare. In view of this, we will select the CCETP as the study object, because it provides an excellent quasi-natural identification strategy which can make us conduct causal identification.

3.1. Model

In this paper, we focus on the impact of CCETP on enterprise innovation and its migration effect. The easiest way to do this is to compare the differences in local innovation directly before and after carbon policy implementation to assess this causal effect. However, this simple approach can not accurately assess the policy effect, since this is not fully taken into account before and after the implementation of the policy, other factors' effect on pilot enterprises; Secondly, this approach does not take into account other policies in the same period which will affect the innovation of non-carbon pilot enterprises, these factors will have a direct effect on enterprise innovation, making the policy assessment errors. Therefore, the traditional method does not accurately assess the impact of CCETP, so we take a more scientific DID method to assess the impact of CCETP on enterprise innovation.

Specifically, this article mainly examines China's 29 provinces and municipalities[1], in which the government selected six

Table 1
Total carbon emissions and market share of pilot.
Data source: The Web of Chinese Carbon Emissions and Trading.

Pilot city	The total of trading volume (10,000-ton)	The share of market (%)
Beijing	486.8	5.50%
Guangdong	2152.7	24.20%
Hubei	3424.1	38.40%
Shanghai	815.3	9.20%
Shenzhen	1745.2	19.60%
Tianjin	184.4	2.10%
Chongqing	73.4	0.80%

provinces and cities as a carbon pilot[2], therefore, the enterprises which belong to these provinces and municipalities become the main investigation of the treatment group, the rest of enterprises which are not located in these provinces and municipalities is considered as control group. The reason why we choose enterprise data is that, firstly, the enterprise as a micro-level individual can provide us with more accurate causal effect; Secondly, enterprise data can provide more detailed innovation data. However, the enterprises and industries in the pilot area are not all regulated by CCETP, and the micro-level enterprise data is not good access, so we have check the list of enterprises that are regulated by CCETP across pilots and manually collect the listed enterprises (which we call regulated enterprises) in these samples. After searching, a total of 989 enterprises are collected, and the number of regulated listed enterprises is 107. Moreover, in order to reduce the estimation bias, according to the enterprise's operating income, net profit, total assets, market value and other variables, we use radius matching method to match them one by one, after matching, the number of regulated enterprises is 53, which is shown in Appendix A.

Therefore, we select variable Pilot to represent the whether this province or city is the pilot or not. If it is a pilot, the value is 1, otherwise, the value is 0. At the same time, the variable Time indicates whether the time is after 2011 or not, if after 2011, the value is 1, otherwise 0. To sum up, we can construct a bidirectional fixed effect measurement model to achieve DID, and assess the net effect of CCETP on enterprise innovation:

$$Innovation_{it} = \alpha + \beta Pilot_i \times Time_t + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{1}$$

where i and t represent the ith pilot and the tth year, where $Innovation_{it}$ is the dependent variable, that is, the level of enterprise innovation. δ_t is the time fixed effect, $\mu_i$is the individual fixed effect in the province, ε_{it} is the error term, and X_{it} is the selected series of control variables. For the above model, the estimated value of the coefficient β is the focus of our concern. It measures the net effect of the CCETP on the enterprise innovation. If $\beta < 0$, it shows that the carbon trading policy has a hindrance to the innovation activities. The policy is actively promoting the innovation of local enterprises.

3.2. Data

This paper mainly assesses the impact of CCETP on local enterprises' innovation activities. And other factors will also affect the enterprise's innovation, therefore, this paper selects the relevant main and control variables based on the micro-enterprise level data and the level of region variables.

3.2.1. The main variable

In this paper, the dependent variable is the enterprise innovation, in order to better measure the enterprise innovation, we select the number of patent applications as the main variable, which is consistent with the previous literature, in order to more fully describe the level of enterprise innovation. In fact, we will use the R&D investment as the main variable in the following to further robust analysis of the results.

3.2.2. Control variable

In order to better control the impact of other relevant factors on enterprise innovation, we have selected a series of control variables based on the micro and macro level. Based on the macro regional level, we select the above-scale industrial enterprises' s R&D personnel input and R&D capital investment variables, which is the basis for innovation. In order to judge the non-linear relationship between R&D investment and enterprise innovation, we also selected the second term of R&D investment funds to examine the non-linear relationship. At the same time, it is also noted that the incentive for innovation is to obtain the economic benefits of innovation, the greater the benefits of innovation, the greater the incentive for innovation to the enterprise. In order to study this incentive well, this paper chooses new products revenue to measure the benefits of innovation. Secondly, taking into account the impact of external environment of enterprises on the enterprise innovation, we select the local technology introduction, FDI and market openness to measure the external environment of the enterprises. Therefore, the article through the calculation of "Total foreign direct investment/regional GDP" represents the FDI, and observes this variable's impact on enterprise innovation. In addition, the opening of the market is conducive to the dissemination of knowledge and technology, its innovation may also have a certain role, so by calculating the "Total import and export trade/regional GDP", we can get the market openness. Moreover, in order to eliminate the bias of the impact, we select the Industrial structure variable, which can significantly reduce the industry differences in provinces and cities. As the region's actual use of foreign direct investment and regional import and export trade volume of the original data are expressed in dollars, so the use of the corresponding annual exchange rate conversion adjustment. And based on the micro-enterprise level, we select some core variables relative to enterprise innovation and performance, which can be more precise control of factors that affect enterprise innovation.

Moreover, the micro-enterprise data come from every regional Development and Reform Commission's regulated enterprise list on the official websites of the government and are collected manually by us, the regulated enterprises' indicators are from CSMAR and Wind databases, and the macro data come from the "China Science and Technology Statistical Yearbook", while the actual use of foreign direct investment in the region, the total import and export trade and regional GDP are from the "China Statistical Yearbook". Table 2 gives a descriptive statistic of the main variables.

Table 2
Descriptive statistics of major variables.

Variable	Description	Calculation method	Mean	Variance
The level of enterprise variables (2009–2015)				
Innovation	Number of patent applications	Number of patent applications (in log)	3.4898	1.5865
Rdperson	Number of R&D personnel	Number of R&D personnel (in log)	1.2861	2.4044
Rdspendsum	R&D investment volume	The total amount of R&D investment (in log)	17.6211	1.5102
Size	The scale of enterprise	Total assess of enterprise (in log)	22.2199	1.9150
ROA	Management level	Total net profit margin	0.0562	0.0548
Revenue	Operating income	Operating income (in log)	21.3193	2.0317
ROE	Business ability	Return on equity	0.0898	0.0890
Profile	Operating profit	Operating profit (in log)	19.0004	2.1261
Rdexpenses	Actual R&D amount	R&D expenses (in log)	− 0.3776	1.6867
Rdrate	R&D investment intensity	R&D investment accounted for operating income ratio (%)	5.9014	5.4491
The level of region variables (2009–2013)				
Innovation1	Number of patent applications	Number of patent applications (in log)	7.6847	1.3615
Innovation2	Number of invention patents	Number of invention patents (in log)	8.6969	1.3888
Per	R&D personnel input	Science and technology activities staff	10.8188	1.2002
R&D	R&D capital investment	Expenditure on science and technology activities	14.0130	1.2844
(R&D)^2	R & D capital investment in the square	Expenditure on science and technology activities (in log) in the square	198.0040	35.3418
Income	New market development level	New product revenue (in log)	16.6266	1.3530
Tech	Technology introduction	Technology introduction fee (in log)	12.2619	1.7181
FDI	Foreign direct investment	(The total amount of FDI / GDP) × 100	32.5766	38.4227
Open	Market openness	(Total import and export trade / GDP) × 100	14.3115	20.9204
Structure	Industrial structure	(Output value of the second industry / GDP) × 100	181.9991	176.6741

4. Empirical test

4.1. The impact of CCETP on regulated enterprise innovation

First, we examine whether the CCETP affects the innovation of the regulated enterprises from an enterprise perspective. The implementation of CCETP on the pilot enterprises can limit carbon emissions, which reduce enterprise performance, and then potentially plays the role of innovation. In view of this, we use the matching listed company data on the model (Abrell et al., 2011) to conduct regression analysis, the specific results shown in Table 3.

It can be seen from the results that the implementation of the CCETP has a significant hindrance to the regulated enterprise innovation, and the obstruction has not changed significantly even after controlling the variables such as personnel input and capital investment. At the same time, it can be seen from Table 3 that the scale of the enterprise has a significant and robust promotion effect

Table 3
The impact of CCETP on regulated enterprise innovation.

	(4.1)	(4.2)	(4.3)	(4.4)	(4.5)
Pilot × Time	− 0.2555***	− 0.2621***	− 0.2929**	− 0.2837**	− 0.2478**
	(0.0902)	(0.0905)	(0.1228)	(0.1229)	(0.1223)
Rdperson		0.0205	0.0100	0.0088	0.0080
		(0.0214)	(0.0216)	(0.0216)	(0.0214)
Rdspendsum			− 0.0969*	− 0.1006**	− 0.0850*
			(0.0501)	(0.0502)	(0.0500)
Size			0.2874***	0.2195**	0.1790*
			(0.0804)	(0.0961)	(0.0962)
Revenue				0.1014	0.1909**
				(0.0788)	(0.0840)
ROA					− 2.1674***
					(0.7553)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes	Yes	Yes
_cons	2.2444***	2.2447***	− 2.3657	− 2.9544	− 4.0905**
	(0.0674)	(0.0674)	(1.7951)	(1.8508)	(1.8744)
N	655	655	484	484	484
F	120.1134	105.1954	60.6734	55.4110	52.5237
r2_a	0.5215	0.5214	0.4967	0.4977	0.5078

Note: Brackets are standard errors (Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 4
The migration effect: the impact of CCETP on non-regulated enterprise and total enterprise in pilot.

	Non-regulated enterprises			The total enterprises		
	(4.1)	(4.2)	(4.3)	(4.4)	(4.5)	(4.6)
Pilot × Time	− 1.1149***	− 1.1051***	− 1.0784***	− 0.6501***	− 0.6597***	− 0.6276***
	(0.1667)	(0.1671)	(0.1675)	(0.1500)	(0.1478)	(0.1467)
Rdperson	0.0350	0.0355	0.0333	0.0129	0.0160	0.0140
	(0.0357)	(0.0357)	(0.0359)	(0.0215)	(0.0212)	(0.0210)
Rdspendsum	0.1004	0.0641	0.0922	− 0.0653	− 0.0925*	− 0.0808*
	(0.1000)	(0.1076)	(0.1122)	(0.0491)	(0.0490)	(0.0489)
Size		0.0951	− 0.0078		0.2686***	0.1570*
		(0.1036)	(0.1207)		(0.0782)	(0.0932)
Revenue			0.1772			0.1994**
			(0.1114)			(0.0820)
ROA			− 1.3181			− 2.0542***
			(0.9805)			(0.7394)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	− 0.4054	− 1.7201	− 3.3893	3.2158***	− 2.0194	− 3.8622**
	(1.6083)	(2.1543)	(2.3455)	(0.8345)	(1.7316)	(1.8206)
N	227	227	227	484	484	484
F	43.2457	38.9663	32.9653	68.2554	64.4841	55.7953
r2_a	0.5862	0.5858	0.5888	0.5012	0.5160	0.5267

Note: Brackets are standard errors.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

on the innovation, which shows that the large enterprise has stronger innovation ability and is easy to innovate compared with the small enterprise.

4.2. The migration effect of the CCETP's impact

The results of Table 3 show that the CCETP has a significant impediment to the regulated enterprise innovation in the pilot. The findings of this conclusion will give us the doubts about whether the CCETP policy will also reduce the pilot within the non-regulated enterprise innovation activities, that is, whether it has a migration effect? In order to answer this question, here we consider the pilot of non-regulated enterprises as a policy intervention object, and remove the regulated enterprises in the sample, in order to test whether the CCETP will reduce the non-regulated enterprise innovation in the pilot. The specific results in Table 4 (4.1)–(4.3). It can be seen that CCETP has a hindrance to the non-regulated enterprises in pilot after the removal of regulated enterprises, and the role is significant at a 1% confidence level. This shows that the CCETP has an obvious migration effect. At the same time, in order to further examine the impact of CCETP on all innovation in the pilot, we also conducted a regression analysis of all enterprises in the pilot as a policy intervention. The results are shown in Table 4 (4.4)–(4.6). It can be seen that the implementation of CCETP significantly reduces the overall innovation.

The conclusion provides two important implications for our analysis: Firstly, due to the migration effect, non-regulated enterprises will also be subject to CCETP intervention, it is because of this “sample” pollution exists, trying to test from the enterprise level of the policy of innovation is not an easy thing. Secondly, because there are a large number of enterprises in the pilots, and the enterprise data we can get only occupy a very small part, so one-sided selection of part of the enterprise will lead to the results of the bias. In view of this, we will proceed from the regional macro point of view, to consider the pilot cities as intervention object and conduct analysis, which can resolve the flaws to be amended.

4.3. The impact of CCETP on regional enterprise innovation

Besides analyzing the regulated and the total enterprises in pilot, now we continue to use the OLS method to evaluate the effect of CCETP on all the regional enterprise innovation, in order to use the DID method to inspect it again. The results are shown in Table 5. It can be seen from the table that CCETP has a significant hindrance to the enterprise innovation, regardless of whether the number of patent applications or the number of invention patents of enterprises measures the enterprise innovation. This shows that the CCETP at the local level does effectively hinder the innovation of local enterprises.

The results shown in Table 5 are only the normal OLS regression. For comparison with this result, we will also use the bidirectional fixed effect model. The results are shown in Table 6 (6.1)–(6.4) are the results of regression of all the samples. It can be seen that the CCETP is still significantly negative for the innovation of enterprise even after controlling the individual effect and time fixed effect of the province. We can see the estimated coefficient of the CCETP in the enterprise innovation declined. But the change degree of the two is not high, indicating that in the quasi-natural experiment, the sample to some extent rules out the policy endogenous

Table 5
Impact of CCETP on regional enterprise innovation: OLS estimation.

	Innovation 1			Innovation 2		
	(5.1)	(5.2)	(5.3)	(5.4)	(5.5)	(5.6)
Pilot × Time	− 0.1516**	− 0.2220**	− 0.1706*	− 0.2363***	− 0.3245***	− 0.2694***
	(0.0580)	(0.0898)	(0.0893)	(0.0622)	(0.0957)	(0.0805)
Time	0.8196***	0.3110***	0.3650***	0.9118***	0.4307***	0.4730***
	(0.0365)	(0.0575)	(0.0610)	(0.0453)	(0.0577)	(0.0561)
Pilot	1.3331***	0.4460***	0.3153**	1.4856***	0.6164***	0.4908***
	(0.4231)	(0.1507)	(0.1372)	(0.4700)	(0.1462)	(0.1466)
Per		0.8678***	0.8704***		0.6769***	0.6830***
		(0.2234)	(0.1895)		(0.1998)	(0.2034)
R&D		− 1.6503***	− 1.2983***		− 1.9339***	− 1.3934***
		(0.5031)	(0.4563)		(0.3837)	(0.4258)
(R&D)^2		0.0662***	0.0399*		0.0810***	0.0544***
		(0.0182)	(0.0209)		(0.0145)	(0.0184)
Income			0.3725**			0.1924
			(0.1802)			(0.1670)
Tech			− 0.0144			− 0.0393
			(0.0332)			(0.0474)
FDI			0.0017*			0.0012
			(0.0009)			(0.0008)
Open			0.0004			0.0044
			(0.0025)			(0.0032)
Structure			− 0.0001			0.0001
			(0.0003)			(0.0003)
_cons	8.0270***	9.0927***	3.2832	6.9459***	11.1060***	5.9052
	(0.2828)	(3.1920)	(3.9738)	(0.2578)	(2.5615)	(3.4933)
N	174	174	174	174	174	174
F	249.0059	200.2469	307.0705	258.2157	226.3463	369.9526
r2_a	0.2029	0.9336	0.9420	0.2558	0.9288	0.9338

Note: Brackets are standard errors (Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

problem. Of course, endogenous issues need to be further validated below.

In addition to the outcome, it can be seen from Table 6 that the inputs required by scientists in the process of technological innovation have a significant role in promoting it and that the financial support needed for innovation is also positive for innovation which is exactly the same as expected. At the same time, the coefficient of the square of the investment in scientific research is obviously negative, which shows that the effect of the investment in scientific research on enterprise innovation shows the inverted "U" type, which shows that the effect of capital investment on enterprise innovation grows firstly and then decreases, which requires in the whole process of innovation, other elements of enterprise also should support the input.

In addition to talent and capital investment, the enterprise innovation of income of the new product on the enterprise innovation has a certain incentive, if the greater the income of new products, the greater the incentive for innovation, enterprises will be more innovated to get rich returns, and vice versa. From Table 6, the coefficient of sales of new products can be seen, it has a positive effect on the innovation of enterprises, and the effect is significant at the level of 10% confidence. The empirical results are in full compliance with the above theoretical analysis. In addition, the technology introduction for local enterprises has a certain degree of inhibition of innovation. The foreign direct investment has a significant effect on the innovation of the enterprise, and the effect has good soundness. Foreign direct investment for local enterprises, provides the necessary funds for innovation and the corresponding talent, and brings new knowledge, technology and advanced management, these factors for the enterprise innovation are important to promote the role. At the same time, it can be seen from Table 6 that the market openness does not have a significant impact on the innovation of local enterprises.

In the meantime, the impact of CCETP in different periods may occur in different changes, we will discuss the dynamic effect of CCETP in Appendix B.

4.4. The migration effect of CCETP on enterprise innovation

The results show that the CCETP has significantly reduced the level of enterprise innovation, which are based on microeconomic enterprise data and regional macroeconomic data. However, due to different industries belonging to different industries, the unique differences between industries potentially affect the causal effect of CCETP on enterprise innovation analyzed by DID method. In order to further eliminate the impact of the unique attributes between the industry and the nature of the enterprise, it will be extended on the basis of model (Abrell et al., 2011), using the DDD model to remove the factors between industries, and accurately

Table 6
Impact of CCETP on regional enterprise innovation: DID estimation.

	Innovation 1			Innovation 2		
	(6.1)	(6.2)	(6.3)	(6.4)	(6.5)	(6.6)
Pilot × Time	− 0.1516**	− 0.1464**	− 0.1020*	− 0.2363***	− 0.2284***	− 0.1641***
	(0.0585)	(0.0604)	(0.0555)	(0.0628)	(0.0641)	(0.0517)
Per		0.2484***	0.2620***		0.3506***	0.3563***
		(0.0839)	(0.0870)		(0.1131)	(0.1132)
R&D		0.0940	1.1155***		0.1562	1.6566***
		(0.1407)	(0.3469)		(0.1372)	(0.4677)
(R&D)^2			− 0.0415***			− 0.0588***
			(0.0148)			(0.0192)
Income			0.1562**			0.1639**
			(0.0717)			(0.0751)
Tech			− 0.0090			− 0.0363**
			(0.0150)			(0.0150)
FDI			0.0019***			0.0027***
			(0.0004)			(0.0005)
Open			− 0.0013			− 0.0026
			(0.0031)			(0.0044)
Structure			− 0.0006***			− 0.0004
			(0.0002)			(0.0003)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	8.2425***	4.3591**	− 4.3055*	7.2014***	1.4022	− 10.3248***
	(0.0282)	(1.6902)	(2.5061)	(0.0343)	(1.7687)	(2.9210)
N	174	174	174	174	174	174
F	187.2173	200.4400	574.9948	114.9310	125.8432	223.8497
r2_a	0.9340	0.9391	0.9461	0.9154	0.9246	0.9355

Note: Brackets are standard errors (Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

evaluate the results, the specific model is as follows:

$$Innovation_{it} = \alpha + \beta Pilot_i \times Time_t \times Industry_i^k + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{2}$$

where $Industry_i^k$ represents the classification of the nature of the enterprise. $k = 1$ means that enterprises are divided into high-pollution enterprises and non-pollution enterprises; $k = 2$ means enterprises will be divided into high-tech enterprises and non-high-tech enterprises; $k = 3$ means that based on nature, the enterprises are divided into state-owned enterprises and non-state-owned enterprises. The explanations of the other variables in the model are the same as the model (Abrell et al., 2011).

First of all, we are based on whether the enterprise belongs to the high pollution enterprise to divide them, if it is a high pollution industry, the value of $Industry_i^1$ is 1, the contrary is 0. The reason why we consider the pollution, because the high pollution enterprise will be affected by CCETP, the greater the intensity of policy regulation, the greater the impact on enterprise innovation. The results are shown in Table 7. In Table 7, (7.1)–(7.3) are mainly the results of the regression of regulated enterprise, and (7.4)–(7.5) is mainly based on the analysis of all the enterprises in the pilot. It can be seen from the results, whether the regulated enterprises or all enterprises are considered as the object of study, excluding the special factors in the pollution industry, CCETP still reduces the enterprise innovation, and the role is significant at the 1% confidence level.

Secondly, taking into account the enterprise innovation not only depends on the enterprise innovation input, more importantly, it also depends on whether the enterprise is an innovative enterprise, that is, whether the it belongs to the high-tech enterprise. In view of this, here we will divide them depending on whether they belong to the high-tech industry or not, if it belongs to the high-tech enterprise, the value $Industry_i^2$ is 1, otherwise 0. The regression result is shown in (8.1)–(8.3) and (8.4)–(8.5) of Table 8. It can be seen from the results, it can be seen from the results, whether the regulated enterprises or all enterprises are considered as the object of study, excluding the special factors in the high-tech industry, CCETP still reduces the enterprise innovation, but the role is not significant.

Finally, we are based on whether the enterprise belongs to the stated-owned enterprise to divide them, if it is a stated-owned enterprise, the value of $Industry_i^3$ is 1, the contrary is 0. The reason for this division is because the state-owned enterprises in China has a policy of preferential and status of the particularity of the local government and policy constraints which may make the state-owned enterprises by the CCETP more impact on the enterprise innovation. The result is shown in Table 9, and it shows that the CCETP also reduces the innovation of state-owned enterprises, even at the level of 1%, even if the enterprise factors are removed. The reason may be that the CCETP is the central government to implement and prepared in 2017 nationwide large-scale promotion, with a strong targeted, which will make the local government must be seriously implemented, so the state-owned enterprises are also affected by the policy.

Table 7
The migration effect of CCETP on high pollution enterprise.

	Regulated enterprises in pilot			The total enterprises in pilot		
	(7.1)	(7.2)	(7.3)	(7.4)	(7.5)	(7.6)
Pilot × Time × *Industry*[1]	− 0.3934***	− 0.3950***	− 1.1776***	− 0.3462***	− 0.3478***	− 0.8490***
	(0.1240)	(0.1241)	(0.3385)	(0.1210)	(0.1210)	(0.2760)
Rdperson		0.0168	0.0071		0.0168	0.0063
		(0.0213)	(0.0210)		(0.0214)	(0.0211)
Rdspendsum			− 0.0893*			− 0.0912*
			(0.0492)			(0.0494)
Size			0.1339			0.1323
			(0.0940)			(0.0944)
Revenue			0.1974**			0.2082**
			(0.0828)			(0.0830)
ROA			− 2.4246***			− 2.2893***
			(0.7436)			(0.7458)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	2.2622***	2.2629***	− 3.0736*	2.2648***	2.2655***	− 3.2474*
	(0.0668)	(0.0669)	(1.8396)	(0.0669)	(0.0670)	(1.8438)
N	655	655	484	655	655	484
F	120.8578	105.7522	54.3645	120.1756	105.1538	53.7576
r2_a	0.5233	0.5230	0.5186	0.5217	0.5213	0.5151

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 8
The migration effect of CCETP on high tech enterprise.

	Regulated enterprises in pilot			The total enterprises in pilot		
	(10.1)	(10.2)	(10.3)	(10.4)	(10.5)	(10.6)
Pilot × Time × *Industry*[2]	0.1230	− 0.0713	− 0.1264	0.1328	− 0.0859	− 0.1463
	(0.1013)	(0.1225)	(0.1210)	(0.0913)	(0.1105)	(0.1088)
Rdperson		0.0030	0.0049		0.0024	0.0037
		(0.0219)	(0.0214)		(0.0219)	(0.0213)
Rdspendsum		− 0.0807	− 0.0928*		− 0.0797	− 0.0913*
		(0.0504)	(0.0500)		(0.0504)	(0.0500)
Size			0.1608*			0.1570
			(0.0961)			(0.0955)
Revenue			0.2082**			0.2154**
			(0.0840)			(0.0842)
ROA			− 2.2815***			− 2.3120***
			(0.7556)			(0.7538)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	2.2741***	3.4973***	− 3.8994**	2.2731***	3.4872***	− 3.9795**
	(0.0676)	(0.8570)	(1.8933)	(0.0674)	(0.8557)	(1.8887)
N	655	484	484	655	484	484
F	117.7194	62.9307	51.8292	117.9532	63.0073	51.9945
r2_a	0.5156	0.4752	0.5036	0.5162	0.4756	0.5046

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

5. Robustness test

In the previous text, we use DID and DDD methods to assess the migration effect of the impact of CCETP on enterprise innovation. Therefore, a series of robustness tests should be conducted and prove the effectiveness of the causal estimation.

Table 9
The migration effect of CCETP on stated-owned enterprise.

	Regulated enterprises in pilot			The total enterprises in pilot		
	(9.1)	(9.2)	(9.3)	(9.4)	(9.5)	(9.6)
Pilot × Time × *Industry*^{3}	− 0.3896***	− 0.8775***	− 0.8154***	− 0.4135***	− 0.7093***	− 0.6415***
	(0.0816)	(0.1269)	(0.1299)	(0.0814)	(0.1321)	(0.1342)
Rdperson		0.0164	0.0159		0.0142	0.0134
		(0.0185)	(0.0183)		(0.0189)	(0.0186)
Rdspendsum		− 0.0249	− 0.0267		− 0.0371	− 0.0390
		(0.0429)	(0.0431)		(0.0438)	(0.0439)
Size			0.1214***			0.1082
			(0.0729)			(0.0741)
Revenue			0.0725			0.1074
			(0.0714)			(0.0721)
ROA			− 2.0770***			− 2.2441***
			(0.6270)			(0.6367)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	2.3193***	2.3158***	− 1.5722	2.3168***	2.6173***	− 1.7026
	(0.0676)	(0.7312)	(1.4635)	(0.0673)	(0.7436)	(1.4888)
N	717	582	582	717	582	582
F	125.6853	99.5899	78.2524	126.7154	93.9097	74.3331
r2_a	0.5122	0.5694	0.5817	0.5146	0.5525	0.5671

Note: Brackets are standard errors (Abrell et al., 2011).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

5.1. Parallel trend hypothesis test

Firstly, one of the important premise is the parallel trend assumption which means that if there is no policy impact, treatment group and control group development trend should be parallel and does not occur systematically difference with time. In this regard, a series of tests will be carried out below and we draw the figures of parallel trend in the Appendix C.

In order to better test the parallel trend, we use the methods commonly used in most of the literature to test the parallel trend in the form of regression, for which the following model is established:

$$Innovation_{it} = \theta_0 + \theta_1 Pilot_i \times Time_t + \sum\nolimits_{\tau \in \{-2,-1\}} \theta_\tau Treat_{it} + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{3}$$

In the above equation, *Treat* is a set of dummy variables, which represent the interaction between the dummy variables of the different years before the implementation of CCETP and the dummy variables of the pilot, so as to examine the policy effect of different years before the environmental regulation. If the coefficients θ_{-2} and θ_{-1} are not significant, then there is no systematic difference between the treatment group and control group before the CCETP was implemented. Otherwise, there is a systematic difference them, and the evaluation using the DID is biased. By using regression of the model, we test whether the regression coefficient is significant to prove the parallel trend or not, the specific results shown in Table 10. It can be seen from the table that CCETP still has a significant negative impact on innovation, regardless of whether or not other variables are controlled or regardless of the indicators to be used to innovate. At the same time, the year effect before policy intervention is not significant, the parallel trend assumption between the treatment group and the control group is required to meet the DID.

Secondly, in order to further illustrate the parallel trend hypothesis by a scientific and rigorous method, the counterfactual test will be taken here to prove the above hypothesis. Specifically, we will test the parallel trend hypothesis by changing the provinces of the policy intervention and the year in which the policy is implemented. The most vulnerable question is that the government may take into account the factors such as the level of development of the provinces, the size of the market and the institutional environment, and give priority to those provinces with good conditions as the pilot objects. It makes the existence of the provinces themselves is inconsistent with the development trend, resulting in policy evaluation bias. In order to solve this problem, we need to test whether there are systematic differences between different provinces. From the pilot sample of the pilot provinces of carbon, it can be seen that most of the pilot cities are concentrated in the eastern and central regions of China. At the same time, compared with the pilots, economically developed and superior provinces are located in the eastern and central regions, thus, starting from the geographical location of the provinces, it is an ideal perspective for examining common trends among provinces.

In view of this, we will examine the impact of CCETP on the enterprise innovation in these areas, as well as other eastern provinces and central provinces which are not carbon pilot provinces. If the CCETP has a significant impact on the innovation of these areas, it shows that there are real differences between different provinces, contrary to the parallel trend hypothesis; On the contrary, it shows that the development trend of different provinces is not because of the provincial economic level, institutional environment and other factors having a systematic difference, which can satisfy the parallel trend hypothesis. The rest of the eastern provinces and

Table 10
Parallel trend hypothesis test.

	Innovation 1			Innovation 2		
	(10.1)	(10.2)	(10.3)	(10.4)	(10.5)	(10.6)
Pilot × Time	− 0.1712*	− 0.1669*	− 0.1007	− 0.2051**	− 0.1987*	− 0.1128
	(0.0866)	(0.0910)	(0.0979)	(0.0894)	(0.0980)	(0.0975)
$Treat_{-2}$	− 0.0403	− 0.0519	− 0.0195	− 0.0144	− 0.0314	0.0156
	(0.0715)	(0.0708)	(0.0829)	(0.0826)	(0.0900)	(0.1012)
$Treat_{-1}$	− 0.0185	− 0.0091	0.0269	0.1079	0.1217	0.1470
	(0.0575)	(0.0571)	(0.0756)	(0.0772)	(0.0777)	(0.0921)
Per		0.2572***	0.2698***		0.3777***	0.3737***
		(0.0853)	(0.0904)		(0.1166)	(0.1188)
R&D		0.0854	1.0965***		0.1307	1.6661***
		(0.1439)	(0.3791)		(0.1438)	(0.4966)
(R&D)^2			− 0.0410**			− 0.0597***
			(0.0161)			(0.0202)
Income			0.1550**			0.1620**
			(0.0720)			(0.0742)
Tech			− 0.0088			− 0.0351**
			(0.0152)			(0.0148)
FDI			0.0018***			0.0026***
			(0.0004)			(0.0005)
Open			− 0.0013			− 0.0032
			(0.0035)			(0.0045)
Structure			− 0.0007***			− 0.0006
			(0.0002)			(0.0003)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	8.2425***	4.3837**	− 4.2042	7.2014***	1.4623	− 10.4165***
	(0.0284)	(1.7274)	(2.5899)	(0.0344)	(1.7763)	(2.9853)
N	174	174	174	174	174	174
F	155.8169	178.9948	492.5122	88.4799	102.0467	201.1965
r2_a	0.9333	0.9386	0.9456	0.9153	0.9252	0.9361

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

central provinces, respectively, can be regarded as a hypothetical treatment group to test its impact on enterprise innovation, the specific return shown in Table 11. From the Table 11 we can see, no matter which indicators to measure enterprise innovation, CCETP on the hypothetical intervention in the province of enterprise innovation do not have a significant impact, while the impact of the remaining variables did not change significantly. This indicates that there is no systematic difference between the treatment group and the control group without considering the impact of the CCETP. It also shows that the results obtained by the DID method are effective.

In order to further test the robustness of the above results, we use the research method of Fan and Tian (2013), Liu and Zhao (2015) to carry out counterfactual examination by changing the specific time of policy implementation. This approach is primarily concerned with the fact that other policies or stochastic factors have an impact on enterprise innovation in addition to the CCETP, which is not linked to the implementation of the CCETP. If these policies or random factors have a certain impact on enterprise innovation, it will lead to the above evaluation results of the error. In order to better eliminate the interference of these factors, we will bring forward the CCETP implementation 2 years in advance, if the CCETP at this time has a significant role in enterprise innovation, which can indicate that the enterprise innovation can be influenced by the implementation of other policies or random factors, rather than the implementation of CCETP results; On the contrary, if its impact on enterprise innovation is not significant, which indicates that the impact of enterprise innovation is impacted by the CCETP, the specific regression results are in Table 12. It can be seen from the table that the advance of CCETP implementation time does not have a significant impact on the innovation of the enterprise, which shows that the reduction of enterprise innovation is not from the role of other policies or random factors, but from the CCETP implementation.

5.2. Sub-sample test

From the above analysis, we can see that the CCETP has a significant effect on enterprise innovation. But is there a difference between the different regions? Or does the effect have the same effect on all regions? In order to further prove the robustness of the results and to answer these questions, the sub-sample test should be considered here. From the implementation pilots of the CCETP, the sample generally can be divided into two categories: one for the municipality directly under the Central Government and the other for China's most developed areas (Beijing, Shanghai, Guangdong). In order to test the existence of heterogeneity, we will use

Table 11
The counterfactual test: change pilot provinces and cities.

	Innovation 1				Innovation 2			
	(11.1)	(11.2)	(11.3)	(11.4)	(11.5)	(11.6)	(11.7)	(11.8)
East × Time	−0.0344	−0.0428			0.0353	0.0414		
	(0.0606)	(0.0548)			(0.0735)	(0.0687)		
Middle × Time			−0.0161	0.0346			−0.0374	0.0140
			(0.0915)	(0.0791)			(0.1094)	(0.1046)
Per		0.2799**		0.2679***		0.3478**		0.3628***
		(0.1016)		(0.0903)		(0.1316)		(0.1213)
R&D		1.2416***		1.3225***		1.9648***		1.9415***
		(0.3511)		(0.3440)		(0.4612)		(0.4100)
(R&D)^2		−0.0467***		−0.0494***		−0.0723***		−0.0706***
		(0.0150)		(0.0142)		(0.0205)		(0.0191)
Income		0.1741**		0.1714**		0.1924**		0.1914**
		(0.0719)		(0.0691)		(0.0738)		(0.0715)
Tech		−0.0098		−0.0093*		−0.0375**		−0.0373**
		(0.0149)		(0.0154)		(0.0151)		(0.0155)
FDI		0.0019***		0.0020***		0.0030***		0.0029***
		(0.0004)		(0.0004)		(0.0005)		(0.0005)
Open		−0.0016		−0.0014		−0.0009		−0.0019
		(0.0041)		(0.0041)		(0.0057)		(0.0059)
Structure		−0.0006***		−0.0007***		−0.0004		−0.0004
		(0.0002)		(0.0002)		(0.0003)		(0.0004)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	8.2425***	−5.5399**	8.2425***	−5.9670**	7.2014***	−12.4154***	7.2014***	−12.5328***
	(0.0289)	(2.3865)	(0.0293)	(2.8168)	(0.0352)	(2.7994)	(0.0350)	(3.0500)
N	174	174	174	174	174	174	174	174
F	167.0254	438.8691	187.2711	437.1358	99.8523	241.7273	86.8174	143.1287
r2_a	0.9296	0.9445	0.9294	0.9444	0.9064	0.9316	0.9065	0.9314

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

these two categories as a point of view, and study whether exists the differences of impacts on enterprise innovation between municipality directly under the Central Government or not, and between developed and non-developed regions. We can see the model (Anger & Oberndorfer, 2008):

$$Innovation_{it} = \alpha + \beta Pilot_i \times Time_t \times Region_i^s + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \quad (4)$$

In the above equation, the variable $Region_i^s$ indicates whether the ith province belongs to the economically developed region ($s = 1$) or the municipality ($s = 2$). If it belongs to the economically developed region, the value of $Region^1$ is 1, and the other provinces have the value 0; similarly, if it belongs to the municipality directly under the Central Government, then the value of $Region^2$ is 1, and vice versa. β measures whether the impact of CCETP on enterprise innovation is regional differences in different areas of economic development and central municipality.

The regression results for model (Anger & Oberndorfer, 2008) are shown in Table 13. There is no significant difference in the impact of CCETP on enterprise innovation in different regions. For the number of patent applications, it can be seen from (13.3) that this effect is stronger in developed regions than in developing regions. Mainly because the developed areas of the original innovation capacity, scope, etc. are higher than the developing areas, so its policy has a wider and greater effect; It can be seen from the (13.4) that the obstruction of the carbon trading policy to enterprise innovation is more pronounced in the municipalities directly under the Central Government, and the effect is significant at the 5% confidence level, possibly because they have a more well-supervised system, which can guarantee the implementation of the CCETP, and it makes these enterprises are subject to greater policy restrictions, thereby reducing their earnings, reducing research investment, and ultimately making the general level of innovation be generally reduced. Based on the above analysis, it can be seen that the estimation of the impact CCETP on enterprise innovation is still robust.

5.3. Falsification test

In order to further explain the decline in the innovation of the pilot provinces is not due to other factors, but due to the implementation of CCETP generated, so we will take the falsification test to the conclusions of this article again by making robustness test. We have noted that the government in the implementation of CCETP at the same time in 2012, selected 9 provinces and cities which are Shanghai, Beijing, Tianjin, Jiangsu, Zhejiang, Anhui, Fujian, Hubei, Guangdong to set up pilot in order to implement the

Table 12
Counterfactual test: change the policy intervention time.

	Innovation 1		Innovation 2	
	(12.1)	(12.2)	(12.3)	(12.4)
Pilot × Time(− 2)	− 0.1145	− 0.0549	− 0.1044	− 0.0272
	(0.0716)	(0.0852)	(0.0765)	(0.0913)
Per		0.2686***		0.3634***
		(0.0909)		(0.1191)
R&D		1.2040***		1.8864***
		(0.3680)		(0.4998)
(R&D)^2		− 0.0456***		− 0.0688***
		(0.0158)		(0.0216)
Income		0.1698**		0.1904**
		(0.0709)		(0.0741)
Tech		− 0.0100		− 0.0376**
		(0.0151)		(0.0151)
FDI		0.0020***		0.0029***
		(0.0004)		(0.0005)
Open		− 0.0003		− 0.0014
		(0.0044)		(0.0064)
Structure		− 0.0006***		− 0.0004
		(0.0002)		(0.0003)
Time effect	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes
_cons	8.2425***	− 5.0634*	7.2014***	− 12.1203***
	(0.0282)	(2.4984)	(0.0342)	(3.0445)
N	174	174	174	174
F	164.9927	429.5189	86.8593	146.8004
r2_a	0.9308	0.9445	0.9072	0.9315

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

business tax to change the value-added tax (TCV) policy. It covers the R&D industries and the information technology industries. In order to prevent the impact of this pilot scheme on the CCETP assessment, we have used this policy as a point of view for falsification test. The specific approach is to regard the provinces and cities of the TCV pilot as the treatment group, and the remaining provinces and cities are regarded as the control group, in the meantime, 2013 is considered as the year of TCV policy and to use the DID to evaluate the causal effect of this policy, and the result is shown as in Table 14. In Table 14, (14.1) and (14.2) are the results of regression of all sample provinces, it can be seen that the TCV policy does not have a significant impact on the innovation of local enterprises. Of course, in order to further align with the CCETP, we excluded the provinces that were subject to CCETP intervention in the TCV pilot provinces and returned to provinces that were subject only to TCV policy interventions. The results are shown in (14.3) and (14.4). The results show that even after the removal of pilot provinces, TCV policy on the role of innovation is still not significant. Thus, it can be shown that the decline in enterprise innovation in the pilot provinces does not come from other factors or policies, but only from the implementation of the CCETP, the falsification test provides a strong evidence for the conclusion.

5.4. *Instrumental variable test*

There may be still potential endogeneity for the problems to be studied in this paper. The reason is that, first of all, due to the availability of current data, there may be omission of important variables in the model, and if the missing variable is related to the random error term, it will lead to the deviation of the estimated result in the model. Secondly, the Chinese government to select the appropriate provinces and cities to carry out carbon pilot, the ultimate goal is to achieve the establishment of an effective and unified carbon market in the whole country in the future. In order to solve the potential endogeneity problem, we will further construct the instrumental variables for the policy intervention variables and use the two-stage least squares method (2SLS) to test the robustness of the above results.

The choice of instrumental variables should satisfy two basic conditions: the instrumental variable is highly correlated with the endogenous variable and is not related to the random perturbation term. In view of the requirements of this condition and the ultimate goal of the implementation of CCETP by the government, we analyze the area of the carbon pilot provinces and find that the government's pilot cities are almost all based on the current major economic zone of China, such as Beijing and Tianjin belong to the Circum-Bohai Sea Economic Zone, Shanghai belongs to the Yangtze River Delta Economic Zone, Chongqing belongs to Chengdu-Chongqing Economic Zone, Guangdong belongs to the Pearl River Delta Economic Zone, Hubei belongs to the central area of the Yangtze River Economic Zone. Based on the purpose of the carbon pilot and the geographical location of the carbon pilot provinces, we have reason to believe that the government chooses these provinces to conduct tests to test the effects of different regions on

Table 13
The sub-sample test of the impact of CCETP on enterprise innovation.

	Innovation 1				Innovation 2			
	(13.1)	(13.2)	(13.3)	(13.4)	(13.5)	(13.6)	(13.7)	(13.8)
Pilot × Time × $Region^1$	− 0.1245	− 0.0457			− 0.2411**	− 0.1467*		
	(0.0965)	(0.0885)			(0.0889)	(0.0765)		
Pilot × Time × $Region^2$			− 0.1143	− 0.0719			− 0.1979***	− 0.1398**
			(0.0718)	(0.0702)			(0.0621)	(0.0573)
Per		0.2612***		0.2689***		0.3481***		0.3685***
		(0.0929)		(0.0914)		(0.1190)		(0.1190)
R&D		1.2607***		1.2321***		1.8555***		1.8275***
		(0.3273)		(0.3411)		(0.4344)		(0.4522)
(R&D)^2		− 0.0481***		− 0.0468***		− 0.0684***		− 0.0667***
		(0.0140)		(0.0145)		(0.0185)		(0.0195)
Income		0.1698**		0.1617**		0.1791**		0.1685**
		(0.0714)		(0.0731)		(0.0755)		(0.0774)
Tech		− 0.0100		− 0.0100		− 0.0382**		− 0.0380**
		(0.0151)		(0.0151)		(0.0152)		(0.0152)
FDI		0.0020***		0.0020***		0.0028***		0.0028***
		(0.0004)		(0.0004)		(0.0005)		(0.0005)
Open		− 0.0017		− 0.0009		− 0.0046		− 0.0020
		(0.0040)		(0.0034)		(0.0057)		(0.0050)
Structure		− 0.0006***		− 0.0006***		− 0.0004		− 0.0004
		(0.0002)		(0.0002)		(0.0003)		(0.0003)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	8.2425***	− 5.2702**	8.2425***	− 5.0634*	7.2014***	− 11.3805***	7.2014***	− 11.3714***
	(0.0287)	(2.4064)	(0.0290)	(2.5276)	(0.0344)	(2.7986)	(0.0352)	(2.9463)
N	174	174	174	174	174	174	174	174
F	172.4885	423.4109	170.9068	534.5027	89.9413	135.6222	119.3760	225.1760
r2_a	0.9311	0.9443	0.9313	0.9449	0.9116	0.9331	0.9109	0.9337

Note: Brackets are standard errors.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

carbon trading policies so that future differentiated carbon trading policies can be implemented throughout the country, that is to say, these carbon emissions and trading pilot provinces and cities have "Demonstration Effect" of the policy. Therefore, the following will construct the instrumental variable from the geographic location. Specifically, we use the geographical distance of the pilot province or city to the economic zone as an instrumental variable. If the province or city belongs to an economic zone, the capital area of the provincial capital will be used as the basis for calculation. The specific method is shown in Table 15.

From the selection of the instrumental variables, it is seen that the instrumental variables constructed in this paper are not related to the innovation of the local enterprises, and these variables are highly correlated with whether the provinces or cities can be selected as the pilot, because the government chooses these pilot provinces or cities after taking into account the special nature of these provinces and cities, trying to assess the different regions of the CCETP response to facilitate the future of the national promotion and implementation of differentiated policies. Therefore, it can be explained that the instrumental variable selected in this paper is in compliance with the requirements. The specific regression model is as follows:

$$\text{The fist stage:} Pilot_i \times Time_t = \rho + \varphi Distance_i \times Time_t + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{5}$$

$$\text{The second stage:} Innovation_{it} = \alpha + \beta Pilot_i \times Time_t + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{6}$$

Table 16 is the result of the two-stage least squares estimation using instrumental variables. It can be seen from the table that the effect of CCETP on enterprise innovation is still significantly negative, and the instrumental variable regression coefficient is compared with the estimated coefficient in previous Tables, the value fluctuates only in a small range. At the same time, the table on the instrumental variables of the statistical test also shows that the instrumental variable to meet the corresponding requirements. Thus, the results in Table 16 further illustrate that the endogenous problems caused by missing variables and bidirectional causal effect are not serious, and the results obtained in this paper are still robust.

6. The further discussion

In the further discussion, we will try to explore how CCETP can curb enterprise innovation and has a migration effect. In view of this problem, we think there are several reasons as follows:

Table 14
Falsification test.

	Innovation 1			Innovation 2		
	(14.1)	(14.2)	(14.3)	(14.4)	(14.5)	(14.6)
Pilot × Time	0.0136	− 0.0286	0.0231	0.0541	− 0.0078	0.0666
	(0.0923)	(0.0794)	(0.0829)	(0.1221)	(0.0992)	(0.1098)
Per		0.2281**	0.2404**		0.3537***	0.3371***
		(0.0810)	(0.0952)		(0.1031)	(0.1150)
R&D		0.1629	1.0437**		0.1994	1.7427***
		(0.1444)	(0.4471)		(0.1431)	(0.5748)
(R&D)ˆ2			− 0.0363*			− 0.0611**
			(0.0182)			(0.0240)
Income			0.1589*			0.1613*
			(0.0780)			(0.0785)
Tech			− 0.0087			− 0.0403**
			(0.0165)			(0.0163)
FDI			0.0019***			0.0025***
			(0.0004)			(0.0005)
Open			0.0011			− 0.0047
			(0.0072)			(0.0091)
Structure			− 0.0007***			− 0.0006
			(0.0002)			(0.0003)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	7.9626***	3.4380*	− 4.2978	6.9005***	0.5929	− 10.9117***
	(0.0335)	(1.8962)	(2.8445)	(0.0416)	(1.7449)	(3.3495)
N	138	138	138	138	138	138
F	140.8969	156.2499	1082.3026	75.4064	106.1578	215.4898
r2_a	0.9309	0.9372	0.9444	0.9137	0.9243	0.9359

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 15
Instrumental variables selection.

Pilot	Geographical location	Instrumental variable construction method
Beijing	Circum-Bohai Sea Economic Zone	(The distance between Beijing and Tianjin) × 0.5
Tianjin	Circum-Bohai Sea Economic Zone	(The distance between Beijing and Tianjin) × 0.5
Shanghai	Yangtze River Delta Economic Zone	(Shanghai area / π)ˆ0.5[a]
Chongqing	Chengdu-Chongqing Economic Zone	(The distance between Chengdu and Chongqing) × 0.5
Guangdong	Pearl River Delta Economic Zone	(Guangzhou area / π)ˆ0.5[b]
Hubei	Yangtze River Economic Zone	(Wuhan area / π)ˆ0.5

[a] Here is a reference to the Poncet (2003) proposed on the province of trade distance calculation method, “Distance = $\sqrt{\text{Area}/\pi}$”.
[b] As for the province, we select the capital of this province which is regarded as the object of the research.

6.1. The reduction of R&D investment

Due to the state's emphasis on carbon emissions and the strict degree of environmental regulation, CCETP in the short term can significantly control the regulation of enterprises' emissions, this means it effectively reduces the enterprise sewage, but also significantly reduces the level of enterprises' performance, which in Shen, Huang, and Liu (2017) article about the impact of CCETP on enterprise's production and proformance has also been confirmed. At the same time, the decline in enterprise profits makes the enterprise's R&D investment will be reduced, which in the short term inhibit the enterprise innovation, this path transmission mechanism is not only for the regulated enterprises, because of the existence of economies of scale, economic agglomeration development and other factors, but also the economic performance of non-regulated enterprises will be affected, so there is a migration effect across different types of enterprises. Now we will focus on CCETP for the impact of enterprises' economic performance, specifically, we consider the mechanism to be as follows:

Firstly, we analyze the impact of CCETP on the enterprise performance, for which the establishment of the following model

$$Firm\ performance_{it} = \alpha + \beta Pilot_i \times Time_t + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{7}$$

where the *Firm performance* represents the economic performance of the enterprise. Here, the operating income, operating profit and

Table 16
Impact of CCETP on enterprise innovation: instrumental variable test.

	Innovation 1			Innovation 2		
	(16.1)	(16.2)	(16.3)	(16.4)	(16.5)	(16.6)
Pilot × Time	− 0.1499***	− 0.1478***	− 0.1021**	− 0.2297***	− 0.2271***	− 0.1583***
	(0.0558)	(0.0531)	(0.0499)	(0.0702)	(0.0656)	(0.0605)
Per		0.2485**	0.2620***		0.3505***	0.3565***
		(0.1029)	(0.0968)		(0.1271)	(0.1175)
R&D		0.0938	1.1153***		0.1564	1.6661***
		(0.1251)	(0.3291)		(0.1545)	(0.3995)
(R&D)^2			− 0.0415***			− 0.0593***
			(0.0123)			(0.0149)
Income			0.1562***			0.1649***
			(0.0519)			(0.0630)
Tech			− 0.0090			− 0.0363***
			(0.0115)			(0.0140)
FDI			0.0019***			0.0027***
			(0.0005)			(0.0006)
Open			− 0.0013			− 0.0026*
			(0.0033)			(0.0040)
Structure			− 0.0006**			− 0.0004
			(0.0003)			(0.0003)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes
N	174	174	174	174	174	174
F	340.0087	277.5697	179.4871	259.6271	220.5769	148.3720
r2_a	0.9203	0.9263	0.9342	0.8977	0.9087	0.9213
The first stage regression						
IV	0.0101***	0.0101***	0.0107***	0.0101***	0.0101***	0.0107***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Cragg-Donald Wald F statistic	359.228	368.147	497.948	359.228	368.147	497.948

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

return on net assets are used to measure the enterprise income, operating profit and business ability. The specific regression results are shown in Table 17. It can be seen that the implementation of CCETP not only reduces the operating income of enterprises, but also significantly reduces the business capacity of enterprises. The results show that the CCETP on the performance of pilot enterprises

Table 17
The impact of CCETP on enterprise performance.

	Revenue	Profile	ROE
	(17.1)	(17.2)	(17.3)
Pilot × Time	− 0.1426*	− 0.1201	− 0.0141**
	(0.0726)	(0.1611)	(0.0064)
Rdperson	0.0135	0.0299	− 0.0007
	(0.0120)	(0.0268)	(0.0011)
Rdspendsum	− 0.0062	0.0786	− 0.0013
	(0.0285)	(0.0660)	(0.0025)
Size	0.6185***	0.4410***	− 0.0027
	(0.0403)	(0.0897)	(0.0036)
ROA	2.9155***	15.0843***	1.5059***
	(0.4021)	(1.0468)	(0.0356)
Year fixed effect	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes
_cons	7.3690***	6.9286***	0.0769
	(0.9345)	(2.1171)	(0.0828)
N	587	538	587
F	59.1989	26.9701	174.8124
r2_a	0.4707	0.2412	0.7537

Note: Brackets are standard errors (Abrell et al., 2011; Aghion et al., 2016).
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Table 18
The impact of CCETP on enterprise research investment.

	Rdexpenses		Rdrate	
	(18.1)	(18.2)	(18.3)	(18.4)
Pilot × Time	− 1.2342*	− 1.2509**	− 1.9622**	− 1.5749**
	(0.6280)	(0.6294)	(0.8023)	(0.6986)
Revenue	− 0.8667**	− 0.9605***		− 3.2369***
	(0.3357)	(0.3619)		(0.4170)
Size	1.2893**	1.3895**		1.2806***
	(0.5229)	(0.5428)		(0.4383)
Rdspendsum	0.6000*	0.5809*		3.6689***
	(0.3060)	(0.3077)		(0.3670)
ROA		2.6134		− 7.6080**
		(3.7289)		(3.7496)
Year fixed effect	Yes	Yes	Yes	Yes
Enterprise fixed effect	Yes	Yes	Yes	Yes
_cons	− 21.5789**	− 21.6333**	4.0594***	− 17.9882**
	(10.4151)	(10.4307)	(0.8412)	(9.1202)
N	284	284	563	561
F	7.1923	6.5640	3.1756	17.9786
r2_a	0.2925	0.2945	0.0484	0.3145

Note: Brackets are standard errors.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

have also significantly inhibited.

Secondly, from the results in Table 17 it can be seen, CCETP significantly reduces the enterprise performance, then will the reduction of the performance also affect the enterprise's research funding investment? In order to test this, we establish the following model:

$$Firm\ R\&D_{it} = \alpha + \beta Pilot_i \times Time_t + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{8}$$

where *Firm R&D* represents the level of scientific research input, in order to carry out in-depth research and measurement of enterprise investment level, we use R&D investment costs and R&D investment accounted for the proportion of operating income to measure the actual R&D investment amount and R&D investment intensity, the specific regression results shown in Table 18, (18.1) and (18.2) mainly examine the effect of CCETP on the investment of enterprise scientific research, while (18.3) and (18.4) examine the effect of CCETP on the strength of scientific research investment. The results show that the policy not only significantly reduces the investment in scientific research, but also reduces the intensity of scientific research investment. The conclusion provides a microcosmic explanation for the reduction of the level of innovation in the enterprise, that is, CCETP reduces the enterprise's economic performance by restricting the carbon emissions of the enterprise and reduces the innovation.

6.2. Lack of incentive for innovation

When the CCETP policy is implemented, enterprises are keen to buy emission quotas through the emissions trading market to achieve their own production, in order to achieve the short-term business stability and the normal operation of production and performances, they do not have sufficient incentives and technical level for R&D investment to achieve technological innovation and improve the productivity of sewage, but to complete the assessment of emission targets and maximize their own production through the quotas trading. This situation can be seen from the significant decline of R&D investment of enterprises after CCETP regulation and the increase of the carbon emissions trading compliance rate.

In Fig. 2, we describe the R&D investment of regulated and non-regulated enterprises in the pilot areas, where the abscissa represents the year and the ordinate represents “R&D accounted for the operating income ratio (%)”. As can be seen from Fig. 2, the R&D investment of regulated enterprises and non-regulated enterprises will be significantly reduced after CCETP policy implementation, which has a migration effect, and the extent of R&D investment reduction of regulated enterprises is higher than that of non-regulated enterprises.

6.3. The alternative effect of environmental subsidy on innovation

To control the excessive emissions of enterprises, Chinese government has implemented multiple environmental subsidies policies which can provide special subsidy for the emission reduction of enterprises. Since 2010, the documents of the environmental subsidy have been conducted up to ten (especially in Appendix D). The government uses financial subsidies to promote energy-efficient

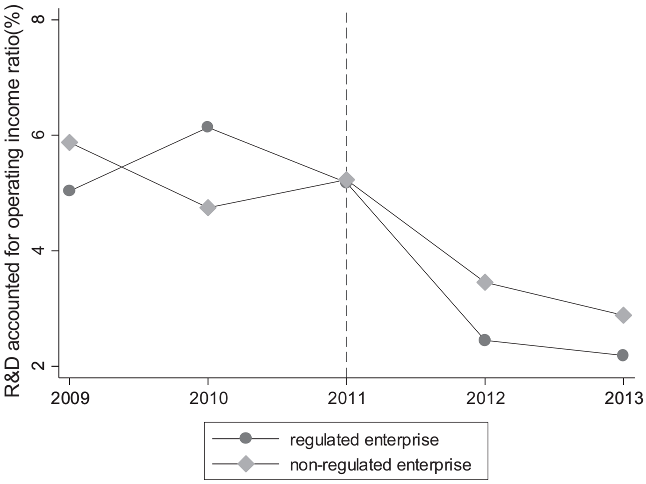

Fig. 2. The R&D investment of regulated and non-regulated enterprises.

products and energy management mechanisms to guide enterprises to reduce emissions. The establishment of environmental subsidies to a certain extent, can reduce the opportunity cost of enterprise sewage, thereby reducing the R&D incentives, which plays an alternative role in enterprise innovation.

7. Conclusion

The regulation of environmental problems and the regulation of greenhouse gas emissions are the common responsibility of mankind, which is not only about the balance of ecosystems, but also on the living conditions of mankind itself. Carbon emissions and trading policies are currently recognized as a way to effectively limit carbon dioxide over-emissions and improve energy efficiency, and how its policy implications are widely debated by researchers. And enterprise innovation as a symbol of environmental regulation should attract much attention. In the current large number of literature research, EU ETS as a normative and more mature policy system, attracting the attention of many scholars and attention. And for its research results: environmental regulation has affected the enterprise innovation, which is still unable to reach a consensus. But except the theoretical predictions and case studies, most of the articles that pass empirical tests support this assertion that carbon emissions and trading policies can significantly contribute to innovation.

And in this paper, the results show that the same environmental regulation policy has migration effect and industrial heterogeneity, and significantly curb the enterprise innovation. This is still true after a series of robustness tests. The current empirical results show that environmental regulation has different effects in different regions, with significant regional heterogeneity. In the meantime, from the dynamic effect of CCETP, the obstacle to the innovation of carbon trading policy is long-term and the obstruction will increase with the execution time, which shows that the CCETP is hindered by regional innovation. The effect has a marginal increase effect over time. And this causal effect of the CCETP on enterprise innovation requires a lot of empirical research to be confirmed and tested.

China as a responsible big country, its determination to control excessive carbon emissions and the urgent need to improve energy efficiency is unquestionable, but the costs that must be faced in the process of reducing emissions need to be mentally prepared and policy-oriented. China's long-term development is inseparable from the improvement of enterprise economic performance, and enterprise economic performance cannot be improved without technological change and innovation capacity. Enterprise innovation as the fundamental driving force of enterprise development and the necessary guarantee, its significance is far-reaching, self-evident. Therefore, within the foreseeable short-term, CCETP will significantly reduce the ability of enterprises to innovate, which still need to get the academic attention and sustained attention, think of the solution and solutions to reduce the enterprise and even the country's economic growth in the process of the cost and obstacles to promote the sustainable development of different economies.

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Appendix A

Table A.1
The regulated enterprises in pilots and matching sample.

	Beijing	Shanghai	Tianjin	Chongqing	Shenzhen	Guangdong	Hubei
A: Pre-match sample							
The number of enterprises in pilot	229	203	41	44	37	353	82
The number of regulated enterprises	44	19	2	5	3	21	13
B: Matched sample							
The number of enterprises in pilot	24	16	1	3	1	29	8
The number of regulated enterprises	19	11	2	0	1	14	6

Appendix B. The dynamic effect of CCETP on enterprise innovation

In this appendix, we provide the dynamic effect of CCETP on enterprise innovation. The above results strongly illustrate the average role of CCETP in enterprise innovation. However, in fact, the CCETP has a certain degree of continuity, its impact on the enterprise is not necessarily effective in the current period, the reason is: on the one hand, for enterprise, the CCETP on the enterprise's scientific research has a direct impact on investment, and changed the original plan of scientific research investment. In the meantime, the enterprise takes a long-term consideration and adjusts the long-term scientific research situation, so the implementation of CCETP plays a long-term role in enterprise's R&D, on the other hand, in terms of scientific research input and output, the current scientific research investment does not necessarily get the current output, there is a clear delay characteristics. Therefore, it can be inferred that the CCETP has a long-term impact on the innovation of enterprises. In order to test this theory, we will examine the dynamic effect of this policy on enterprise innovation. We set model (B.1) on the basis of model (Abrell et al., 2011), as follows:

$$Innovation_{it} = \alpha + \sum \beta_k PilotYear_{it}^k + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{B.1}$$

In the above equation, the variable $Pilot\_Year_{it}{}^{k}$ represents the annual dummy variable (where $k = 1, 2$) after the implementation of the CCETP in the pilot province. For example, this policy was issued in 2012, then $k = 1$ in 2013, variable $Pilot\_Year_{it}{}^{1} = 1$, and 0 for the rest of the year. β_k measures the impact of this policy on enterprise innovation after the policy implementation for the first year. At the same time, the control variables added to the model are the same as those in the model (Abrell et al., 2011), and the outcome is shown in Table B.1.

Table B.1
Impact of CCETP on regional enterprise innovation: the dynamic effect testing.

	Innovation 1			Innovation 2		
	(8.1)	(8.2)	(8.3)	(8.4)	(8.5)	(8.6)
$Pilot\_Year_{it}{}^{1}$	−0.1474***	−0.1402***	−0.1034***	−0.2445***	−0.2339***	−0.1775***
	(0.0479)	(0.0456)	(0.0363)	(0.0597)	(0.0567)	(0.0405)
$Pilot\_Year_{it}{}^{2}$	−0.1710***	−0.1662***	−0.1353**	−0.2541***	−0.2472***	−0.2114***
	(0.0519)	(0.0502)	(0.0517)	(0.0659)	(0.0570)	(0.0590)
Per		0.2373***	0.2519***		0.3335***	0.3401***
		(0.0838)	(0.0852)		(0.1113)	(0.1098)
R&D		0.1107	1.1529***		0.1816	1.7134***
		(0.1380)	(0.3376)		(0.1297)	(0.4586)
(R&D)^2			−0.0426***			−0.0604***
			(0.0140)			(0.0188)
Income			0.1630**			0.1741**
			(0.0716)			(0.0760)
Tech			−0.0108			−0.0389**
			(0.0155)			(0.0152)
FDI			0.0019***			0.0027***
			(0.0004)			(0.0005)
Open			−0.0020			−0.0036
			(0.0030)			(0.0042)
Structure			−0.0006***			−0.0004
			(0.0002)			(0.0003)

Time effect	Yes	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes
_cons	8.2425***	4.2493**	− 4.5966*	7.2014***	1.2390	− 10.7643***
	(0.0285)	(1.6849)	(2.4611)	(0.0343)	(1.7893)	(2.8710)
N	174	174	174	174	174	174
F	219.7084	224.7799	614.1171	115.5221	130.6504	194.2416
r2_a	0.9336	0.9387	0.9463	0.9148	0.9241	0.9363

Note: Brackets are standard errors.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

The regression results in Table B.1 show that the CCETP has a hindrance to the innovation, regardless of the number of patent applications or the number of invented patents. From the dynamic effect of CCETP, the obstacle to the innovation of this policy has a long-term effect and the obstruction will increase with the execution time of policy. The effect has a marginal increase effect over time. Specifically, the coefficient of $Pilot\_Year_{it}^1$ and $Pilot\_Year_{it}^2$ in the comparison table can be seen that after two years of policy implementation, the hindering effect on enterprise innovation is greater than that after one year of implementation. The dynamic effect test shows that the CCETP has a significant hindrance to the innovation activities of the local enterprises, and the effect is gradually increased with the passage of time.

Appendix C. The parallel trend hypothesis

According to most of the previous literature on the parallel trend of the test method, we draw the treatment group and the control group between the variable comparison chart, in order to explain the policy before and after the implementation of changes. We draw the trend of patent applications and inventions in provinces between provinces implementing CCETP and provinces that do not have it. See Fig. C.1 and Fig. C.2. As can be seen from the figure: Firstly, regardless of the number of patent applications or the number of patent inventions to measure the level of innovation, can be drawn in 2012 before the implementation of CCETP, treatment provinces and control provinces between the enterprise innovation have the same trend, almost completely parallel; Secondly, after the implementation of the policy, the policy treatment provinces and control provinces of the development trends have a significant difference. Specifically, the number of patent applications and the number of patent inventions in the CCETP provinces have slowed down, and the slope of the curve is flat and there is a growing trend. This is consistent with the results of the dynamic effect test above; for those provinces that have not been affected by the CCETP, their regional innovation still maintains the original development trend and follows the path of natural evolution. In short, Fig. C.1 and Fig. C.2 intuitively shows that CCETP on the enterprise innovation have a certain role.

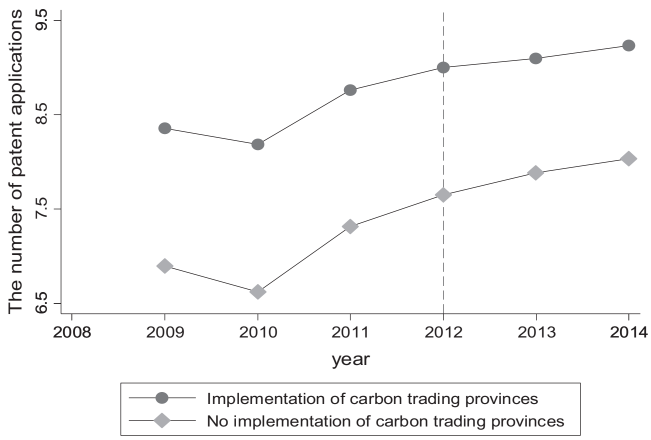

Fig. C.1. The CCETP pilots and non-CCETP pilots patent applications' trends change.

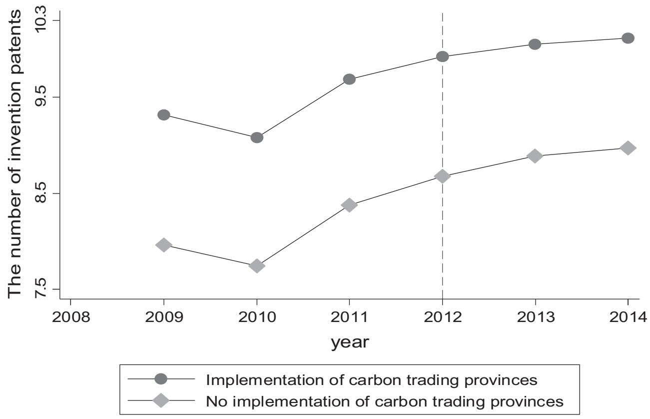

Fig. C.2. The CCETP pilots and non-CCETP pilots patent inventions' trends change.

Appendix D. The key environmental subsidies policies

Chinese government has implemented multiple environmental subsidies policies which can provide special subsidy for the emission reduction of enterprises. Among them, the key policy mainly includes:

1. On February 6, 2010, the State Council issued "on further strengthening the elimination of backward production capacity of the notice".
2. On April 20, 2011, the State Ministry of Finance, Ministry of Industry, and the State Energy Bureau jointly issued "to eliminate backward production capacity of the central financial incentives management approach".
3. On August 31, 2011, the State Council issued the ""second five" comprehensive energy-saving emission reduction program".
4. On August 6, 2012, the State Council issued "energy-saving emission reduction 'the twelfth five years plan'".
5. On May 15, 2014, the State Council issued "2014–2015 energy-saving emission reduction low-carbon development action program".
6. On May 12, 2015, the Ministry of Finance issued "energy-saving emission reduction subsidy funds Interim Measures".
7. On January 22, 2016, the National Development and Reform Commission issued the "Do a good job on the national carbon emissions trading market to start the focus of the notice".

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