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Environmental regulation, innovation quality and firms' competitiveness-Quasi-natural experiment based on China's carbon emissions trading pilot

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ABSTRACT

In the study of the “Porter Hypothesis”, scholars explored the impact of different forms of innovation on the firms' competitiveness, but did not distinguish between innovations on the difference in patent quality. In addition, relevant research only regards innovation as a mediator between environmental regulation and competitiveness, and doesn't take into account innovation induced by environmental regulation, can only promote competitiveness under the constraints of environmental regulation. That is to say, environmental regulation not only induces innovation, but also moderates innovation to promote competitiveness. In view of this, we use panel data of A-share listed firms in China from 2006 to 2016, and adopt propensity score matching and different in different (PSM-DID) model to empirically test the inductive effect and moderating effect. The results show that CETS cannot only improve the quantity and quality, but also significantly enhance the firms' market value; innovation itself cannot enhance the firms' market value, but the interaction with CETS can promote the firms' market value. In addition, the CETS has a stronger inductive effect on innovation of state-owned shares firms, but the positive moderating effect on high-quality innovation and competitiveness only exists in non-state-owned shares firms.

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1. Introduction

In recent years, in order to cope with global warming, the Chinese government has actively assumed the responsibility for major powers. In June 2013, seven CETS pilots were launched in Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Shenzhen and Hubei. At the same time, it is also clearly stated in the “13th Five-Year Plan” that by 2020, the carbon dioxide emissions per unit of GDP will be 40%-45% lower than that of 2005, and the target of achieving peak CO₂ emissions by 2030 is expected

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(Tollefson, 2016; Weng et al., 2018). It is foreseeable that a low-carbon economy will become an inevitable trend for the sustainable development of China's economy in the future. However, China is also facing many "challenges" in the "opportunities" of low-carbon sustainable development. According to the World Energy Statistics Yearbook 2017, China's primary energy consumption of 2016 is 4.36 billion tons of standard coal, of which coal accounts for 62%. Compared with the peak of 76% in 2008, although it has decreased, it also means that the energy consumption structure dominated by coal is still difficult to change fundamentally in the short term (Zhang et al., 2017). Moreover, with the acceleration of industrialization and urbanization in China, the total energy consumption will increase at an average annual rate of 2.5% in the future. Therefore, under the dual pressures of energy structure being difficult to optimize in the short term and energy consumption increasing continuously, whether and how to coordinate the dual objectives of greenhouse gas emission mitigation and economic development. It has become an important issue to be solved urgently by the Chinese government and academia.

According to Porter and Linde (1995), reasonable environmental regulation can stimulate firms' technological innovation, and make up for compliance costs by means of energy saving and product quality improvement brought by technological innovation, in order to improve environmental quality while promoting the firms' competitiveness, namely the so-called "Porter Hypothesis". It can be seen that the realization of win-win economic and environmental depends to a large extent on whether the CETS can promote technological innovation and adoption. However, in the existing empirical research on the "Porter Hypothesis", scholars mostly affirmed the role of environmental regulation to stimulate firm innovation, but there is a big controversy about whether environmental regulation can effectively improve firm performance or competitiveness (Hille & Möbius, 2019; Yuan et al., 2017; Zhao & Sun, 2016). Even in some studies, technological innovations caused by environmental regulations are not supported to bring about an increase in firm performance or competitiveness (Ambec et al., 2013; Gilli et al., 2014; Rexhäuser & Rammer, 2014). This is because, in strict environmental regulations, firms have to invest the elements (labor and capital) that were originally used for productive activities in non-productive activities to reduce pollution emissions (Ambec et al., 2013; Gray & Shadbegian, 1998). Although this process contributes to the creation and use of new technologies (Ghosal et al., 2014; Nesta et al., 2014), but because the firm innovation strategy is not consistent, it will choose different forms of technological innovation. And the difference in the form of technological innovation will ultimately be reflected in the difference in the compensation for the cost of the regulation (Hu et al., 2017; Porter & Linde, 1995). If the performance of the technology innovation chosen by the firm cannot make up the cost, then it will still cause loss of competitiveness (Rexhäuser & Rammer, 2014). Therefore, it can be said that the existence of the "Porter Hypothesis" depends largely on which form of technological innovation the firm chooses.

Considering that China has experienced explosive growth in the number of innovations characterized by patents in recent years, there is still a big gap in terms of the innovation quality compared with developed countries in Europe and America (Hu et al., 2017). Therefore, this paper divides firm innovation into innovation quantity

and innovation quality based on patent characteristics. It is generally believed that the higher the firms innovation quality, the more obvious its competitive advantage in the market (Hall et al., 2005; Lanjouw & Schankerman, 2004). But in reality, some firms tend to apply for a large number of invalid patents for low-quality innovation due to strategic competition (Thoma, 2013). Especially in the absence of major changes in the market environment, if the technological innovation of the firm is too advanced, it will not be recognized by the market, but also the loss of competitiveness due to waste of resources (Hsieh, 2013). Then, at the time of China's low-carbon economic transformation, the CETS, as an external pressure imposed by the government on technological innovation, can induce firms to turn to high-quality innovation? And can this kind of innovative strategy conversion be recognized by the market, which will help the firm to improve its competitiveness?

Compared with the existing literature, the possible marginal contributions of this paper can be summarized as follows. (1) on the identification of innovation. In this paper, the innovation level is measured by the innovation quantity and the innovation quality. The patent application count is used as the innovation quantity, and the invention patent application, utility model patent application and design patent application represent the from high to low innovation quality. On this basis, this paper also measures the value dimension of innovation quality by regression of firm's market value to patent. (2) on the types of environmental regulation. This paper takes China's carbon emission trading pilot policy as a quasi-natural experiment to examine the impact of the CETS on the quality of Chinese firms' innovation. (3) In the empirical strategy. This paper not only examines the inductive effect of CETS on firm technology innovation and the mediating effect of technological innovation on CETS and firm competitiveness, but also examines the regulatory effect of CETS on technological innovation and firm competitiveness. (4) in terms of data and methods. We use the 2006-2016 China A-share listed firms data as a research sample. In addition, we first use Prosperity score matching (PSM) to match the samples, and then use different in different (DID) model to regress the matched sub-sample, namely PSM-DID model. The reason is mainly from two aspects. On the one hand, it avoids the result bias of the model endogeneity. On the other hand, it overcomes the defect that the "treatment group" and the "control group" have common trend assumptions in the ordinary DID model.

The remainder of this paper is organized as follows. [Section 2](#) reviews the development history of CETS and the development status of China's CETS, and introduces the existing research on "porter hypothesis", then deduces the research hypothesis of this paper. [Section 3](#) introduces research methods and model setting. [Section 4](#) introduces the data and variable. [Section 5](#) presents empirical results. In [section 6](#), we provide heterogeneity test and robustness test. Finally, the discussion and conclusion in [section 7](#).

2. Institutional background and theoretical framework

2.1. Institutional background

Since the signing of the Kyoto Protocol in October 1997, the new concept of achieving greenhouse gas emission reduction through market mechanisms has been continuously developed (Weng et al., 2018). Especially in the period of 2002-2005, the

United Kingdom, Australia and the European Union have established carbon trading markets, marking the realization of carbon trading from concept to practice. The so-called carbon emissions trading refers to the fact that the firm buys (sells) additional (excess) carbon emission rights in the market based on its own carbon emission allowance based on the government's total carbon emissions. It is generally believed that the nature of the products that give carbon emission rights will have an impact on the production decisions of firms (Zhang et al., 2017). In addition, carbon trading not only has higher emission reduction efficiency than traditional command-and-control emission reduction tools, but also can optimize energy structure through price transmission mechanisms (Fang et al., 2018). At present, the EU's emissions system, the world's largest multi-country CETS, covers 24 countries and more than 12,000 industrial firms (Calel & Dechezleprêtre, 2016), contributing about 80% of the world's trading volume to 490 million euros (Keohane et al., 2017). Other carbon trading markets, such as California, Tokyo, New Zealand and South Korea, are regional CETS that aim to achieve experience for the effective docking with other CETS to form a global unified CETS through the operation of the regional or national CETS.

Recently, China is also actively exploring the establishment of a domestic CETS to achieve a market-oriented environmental regulation of greenhouse gas emission reduction. There are two reasons, on the one hand, low-carbon development has become a global inevitable trend, and financial innovations derived from carbon exchanges are considered to be new economic growth points in the future (Song et al., 2018). On the other hand, possessing the largest carbon resources in the world, China undoubtedly is the main subject in the international carbon market (Liu et al., 2015). However, China finds itself in an awkward and passive position when entering this market due to the lack of a multi-level carbon trading market with price discovery and resource allocation functions. So as to many Carbon Certified Emission Reductions sold to developed countries at low prices are packaged into high-end carbon financial products and resold for more profit, resulting in the loss of carbon assets (Zhang et al., 2017). In October 2011, the National Development and Reform Commission of China issued the "Notice on Launching Pilot Work on CETS Rights", officially approving carbon trading pilots in Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong and Shenzhen, and launched carbon emissions trading in these seven provinces and cities in 2013. Among them, the industries constrained by carbon emissions are mainly eight high-carbon industries such as steel, electric power, chemical, construction, paper, non-ferrous metals and aviation (Wang & Lin, 2016; Xu et al., 2016). As of December 2016, the volume of carbon dioxide in seven carbon trading pilots reached 160 million tons, with a turnover of nearly 2.5 billion yuan (Weng et al., 2018). Although the size of carbon trading in China's pilot provinces and cities is smaller than that of EU emissions trading, it is growing rapidly. Especially in December 2017, with the issuance of the National Carbon Emissions Trading Market Construction Plan (Power Generation Industry), it means that the establishment of a national CETS with the power generation industry as a breakthrough will be fully launched. By then, China's carbon trading market will reach 4 billion tons, twice the European carbon trading market, and is expected to become the world's largest CETS (Weng et al., 2018).

2.2. Theoretical framework and research hypothesis

At present, the research on the “Porter Hypothesis” has emerged in large numbers. This paper will sort out and interpret the existing literature from the relationship between environmental regulation and the relationship between firm innovation quality, innovation quality and firm competitiveness, and derive the research hypothesis.

2.2.1. Induced effect of environmental regulation

Since Porter and Linde (1995) pioneered the “Porter Hypothesis”, that is, strict environmental regulation can induce firms to carry out technological innovation, in order to make up for the “cost of compliance”, but also to enhance the competitiveness of firms. Since then, a lot of confirmatory research on the “Porter Hypothesis” has emerged. Although there is controversy over whether strict environmental regulation can enhance the competitiveness of firms, it is more consistent that most studies show that reasonable environmental regulation does induce technological innovation in firms. However, with the deepening of research, scholars have classified the technological innovation more carefully, and found that environmental regulation does not promote all types of innovation, but has a biased induction. In other words, environmental regulation has changed the firm’s original innovation strategy. Some scholars have divided the technology into pollution-based technology and clean-type technology based on the influence of technology on environmental quality. It has been verified theoretically and empirically that strict environmental regulation can indeed induce firms to shift from pollution-based technological innovation to clean technological innovation (Acemoglu et al., 2012; Johnstone et al., 2017; Rubashkina et al., 2015). In addition, some scholars have divided technological innovation into process innovation and product innovation. They believe that environmental regulation has a significant effect on both types of innovation, but relatively speaking, the impact on firm process innovation is more powerful (Guo et al., 2018; Hu et al., 2017; Triguero et al., 2013). Considering that China has achieved explosive growth in the number of patent-based innovations, there is still a big gap in terms of the innovation quality compared to developed countries in Europe and America (Hu et al., 2017). Based on the patent characteristics, this paper divides firm’s innovation into innovation quantity and innovation quality, which undoubtedly conforms to the problem that innovation quality lags behind innovation quantity in China.

In addition, Existing literature indicates that the choice of environmental regulation tools is also a key factor affecting firm innovation strategies (Bergek & Berggren, 2014). It is generally believed that market-based environmental regulation tools give firms greater flexibility in pollution reduction and thus more incentives for technological innovation than command-and-control environmental regulation tools (Johnstone et al., 2017; Ren et al., 2018; Tang, 2015). Anderson et al. (2010) found through questionnaires that nearly half of the firms in the CETS have updated their existing production facilities, and most of them have optimized their production processes. Similarly, Borghesi et al. (2015) based on Italian data also shows that the CETS can significantly promote firm green technology innovation. At the same time, however, some scholars have found that the European CETS has only a 2% improvement in firm low-carbon patent behavior, indicating that the green innovation effect

of environmental regulation has an exaggerated component (Calel & Dechezleprêtre, 2016). Bel and Joseph (2018) explained this that the lack of supply of carbon trading quotas in the EU caused the carbon price to be low, which would not restrict the production behavior of firms, and ultimately it was not conducive to firms to adopt low-carbon technology. Although China's CETS is still in its infancy, and the carbon trading quota and carbon rights pricing mechanism need to be improved, in view of China's previous experience in the operation of the Clean Development Mechanism (CDM), and the carbon emissions trading pilots are selected in economically developed regions, which are certain degree of comparability with European countries. Therefore, the hypothesis H1 of this paper is proposed:

H1: The CETS not only promotes the increase in the number of firm innovations, but also induces firms to turn to high-quality innovation.

2.2.2. Moderated effect of environmental regulation

Patents as "successful" innovations Hall et al. (2005) are often used to measure the innovation quality or technology (Kim et al., 2018). However, due to data availability and the diversity of patent features, different studies have used different characteristics of patents to measure the innovation quality. It is more common to use patent citations to measure the quality of Chinese innovation (Boeing & Mueller, 2016; Rong et al., 2017), but the problem is that patents that are applied earlier may have more citations than patents that are applied late, and are likely to have nothing to do with the innovation quality. To solve this problem, Fisch et al. (2017) used the time span of patents from the time of application to the first time to evaluate the quality of patents. In addition, considering that a single indicator is difficult to fully reflect the innovation quality, Lanjouw and Schankerman (2004), Schettino et al. (2013) use principal component analysis to construct a comprehensive index representing the innovation quality by using the four patent characteristics of the same family, such as patent size, patent application scope, forward and backward patent citation. However, no matter what indicators and methods are used, the conclusions are that the quality of Chinese patents is lower than other countries.

At the same time, some scholars have emphasized that intellectual property rights (IPR) not only is a major driver of technological competitiveness and sustainable business operation, but also enables firms to generate additional considerable profit (Fisch et al., 2017; Hsieh, 2013). That is to say, innovation quality includes two dimensions of technology and value, and there is a significant positive correlation between these two dimensions (Hall et al., 2005; Lanjouw & Schankerman, 2004). However, some scholars have pointed out that due to the existence of market failures, high-quality innovation may not necessarily bring high returns to firms (Lanjouw & Schankerman, 2004). Especially in the absence of major changes in the market environment, if the technological innovation of the firm is too advanced, it will not be recognized by the market, but also the loss of competitiveness due to waste of resources (Hsieh, 2013), in other words, high quality innovation is not automatically recognized by the market. Therefore, the research hypothesis H2 of this paper is proposed:

H2: The impact of high-quality innovation on firm competitiveness is uncertain, either positive or negative.

At present, as the Chinese economy has changed from a past extensive development model to a critical period of emphasis on development quality, development concepts such as “ecological civilization construction”, “green development” and “high quality development” have also appeared in the Chinese government work report and in the “13th Five-Year Plan”. This also shows that China’s market environment is undergoing tremendous changes. Moreover, with the deepening of the academic research on the “Porter Hypothesis”, more and more evidence shows that under strict environmental regulations, although technological innovations measured by comprehensive indicators have not significantly promoted the market value or competitiveness of firms, they have even negative effects (Hille & Möbius, 2019; Zhao & Sun, 2016). However, in the empirical study of rigorous classification of technological innovation, different types of technological innovations have exerted different innovation compensation effects on “following costs” (Hu et al., 2017), resulting in green technologies induced by environmental regulation. The conclusion that there is a positive relationship between innovation and the market value or competitiveness of the firm (Yuan & Xiang, 2018). Combined with the theoretical analysis of the relationship between environmental regulation and innovation quality, it also means that environmental regulation can accelerate the recognition of high-quality innovations by the market, enabling firms to gain market power and thus bring excess profits to firms.

Finally, the hypothesis H3 of this paper is proposed:

H3: The CETS plays a positive role in moderating innovation quality and competitiveness, and can accelerate the recognition of high-quality innovation by the market, which in turn is conducive to the competitiveness of firms.

3. Method and empirical model

3.1. Method

In order to study the policy effects, most of the existing literatures use the DID model. The advantage of DID model is that the sample is divided into “treatment group” and “control group” according to the time and object of policy action, so that the policy effect can be evaluated. However, considering the following two reasons, directly comparing the CETS pilot firms and non-CETS pilot firms as “treatment group” and “control group” may lead to deviations in results. (1) the non-randomness of pilot selection of CETS cannot be ruled out. On the one hand, from the perspective of industries selected for CETS pilot, most of the industries constrained by carbon emissions are high-carbon industries and sunset industries. On the other hand, CETS pilot is mainly in the provinces and cities with representative degree of regional economic development. It is generally believed that the higher the degree of economic development, the more attention will be paid to energy conservation and greenhouse gas emission mitigation (Zhang et al., 2017). (2) part of the difference between CETS pilot and non-CETS pilot may be caused by other non-observable factors that do not change with time, resulting in the failure of the “treatment group” and the “control group” to meet the common trend hypothesis of DID model, also causes deviations in the empirical results.

Based on this, the paper refers to method of Löschel et al. (2019) using the PSM-DID model for estimation. Firstly, we use the prosperity score match (PSM) to find the “control group” similar with the CETS pilot firms to eliminate the selectivity of sample, so that the “treatment group” and the “control group” have a common trend. Then, the real policy effects of CETS are estimated with DID method, which can ensure the accuracy of empirical results to a large extent. The matching process is as follows.

First, the propensity scores of the “treatment group” and the “control group” were estimated based on the Logit model. The aim is to reduce the multi-dimensional differences between the “treatment group” and the “control group” individuals, in order to facilitate the matching of subsequent tendency scores. As shown in formula (1):

$$P(X) = \Pr(T = 1|X) = \frac{\exp(\beta X')}{1 + \exp(\beta X')} \quad (1)$$

where, $X = (x'_1, x'_2, x'_3, \dots, x'_n)'$ is the control variable matrix, x'_i is the i -th control variable vector. Referring to existing research, we choose firm size (Size) and its square term (Size²), age (Ages), asset-liability ratio (Leverage), ownership structure (SOE) and ownership concentration (COECEN) as control variables. $P(X)$ is the propensity score of the “treatment group” and the “control group” under the control variable matrix X .

Second, the “treatment group” and the “control group” are matched or resampled according to the matching method. The purpose is to calculate the distance or weight between the “treatment group” and the “control group” sample by the propensity score, and then find the counterfactual sample similar to the “treatment group” from the “control group”. This paper uses the nearest neighbor matching method within the caliper range. The specific process is shown in Equation (2):

$$D(m, n) = \min_n |P_{1i} - P_{0j}| \leq \varepsilon \quad (2)$$

where P_{1i} and P_{0j} are the propensity scores of the i -th “treatment group” and the propensity score of the j -th “control group”, respectively, and ε is a predetermined tolerance for matching or a caliper. In this paper, according to Rubin (1985), one-quarter of the standard deviation of the propensity values of the sample estimates is used as the caliper size (namely $\varepsilon \leq 0.25\sigma$, where σ is the standard deviation of the propensity value of the sample estimate)

Third, a balanced test is performed on the matched samples. The aim is to ensure that there is no significant statistical difference in covariates between the “treatment group” and the “control group” after matching. Generally, it is examined by the “standardized differences” or “standardized bias” of each covariate, as shown in Formula (3):

$$\frac{|\bar{x}_1 - \bar{x}_0|}{\sqrt{S_{1x}^2 + S_{0x}^2} / 2} \quad (3)$$

where S_{1x}^2 and S_{0x}^2 are the sample variances of the “treatment group” and “control group” covariates x , respectively. It is generally required that this standardization gap does not exceed 10%, and if it is exceeded, the second or first step is repeated until there is no significant difference.

Finally, the matched samples are used for DID estimation. The purpose is to estimate the impact of CETS on the firms’ innovation quality, on the basis of eliminating the shortcomings of sample non-random selection.

3.2. Empirical model

Based on the above research method, in order to test the research hypothesis H1, the model (4) is set in this paper. For the choice of the timing of the implementation of the CETS, refer to the Zhang et al. (2017), with 2012 as the starting year for the pilot implementation of the CETS.

$$INQ_{i,j,k,t} = \alpha_{i,j,k,t} + \delta \cdot CETS_{i,j,k,t} + \gamma \cdot Control_{i,j,k,t} + Prov_j + u_k + v_t + \varepsilon_{i,j,k,t} \quad (4)$$

where the subscripts i , j , k , and t represent the firm, province, industry, and year, respectively. $INQ_{i,j,k,t}$ is the innovation quantity and innovation quality matrix. $CETS_{i,j,k,t}$ is a 0-1 binary variable, when the sample is “treatment group”, then $CETS_{i,j,k,t} = 1$, otherwise it is 0. $Control_{i,j,k,t}$ is the control variable matrix, including firm size (Size) and its square term ($Size^2$), business age (Ages), asset-liability ratio (Leverage), ownership structure (SOE) and ownership concentration (COCEN). Because the innovation quality varies greatly between different regions and different industries, this paper also controls the individual effects of the industry, province and time, namely u_k , $Prov_j$ and v_t . $\varepsilon_{i,j,k,t}$ represents a disturbance term. In addition, in order to explore whether the CETS can promote the market value of firms and test research hypotheses H2 and H3. This paper constructs a model (5) and a model (6).

$$MV_{i,j,k,t} = \alpha_{i,j,k,t} + \delta \cdot CETS_{i,j,k,t} + \gamma \cdot Control_{i,j,k,t} + Prov_j + u_k + v_t + \varepsilon_{i,j,k,t} \quad (5)$$

$$MV_{i,j,k,t} = \alpha_{i,j,k,t} + \delta \cdot CETS_{i,j,k,t} \times INQ_{i,j,k,t-1} + \beta \cdot INQ_{i,j,k,t-1} + \gamma \cdot Control_{i,j,k,t} + Prov_j + u_k + v_t + \varepsilon_{i,j,k,t} \quad (6)$$

where $MV_{i,j,k,t}$ is the market value. At the same time, considering that the impact of innovation on market value may take a certain amount of time, this paper uses a lagging period of innovation quantity and innovation quality variables $INQ_{i,j,k,t-1}$.

4. Data and variable

4.1. Data Source and processing

This paper takes all the A-share listed firms in China as the initial sample from 2006 to 2016. The patent application data comes from CSMAR database, and other

financial indicators come from the Wind database. And we deal with the raw data as follows.

1. **Sample selection:** In view of the CETS, it only covers eight pilot industries such as petrochemical, chemical, building materials, steel, nonferrous metals, paper, electricity and aviation. Therefore, the first-level sample selected in this paper only covers these eight industries, and listed firms in seven pilot areas including Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Shenzhen and Hubei. as the “treatment group”, and other samples as “control group”.
2. **Missing value and outlier processing:** Pre-extract samples with missing values of control variables, but in order to ensure sufficient sample size, the missing data of patent application, invention patent application, utility model patent application, and design patent application is assigned a value of zero. At the same time, in order to eliminate the influence of extreme values, Winsorize processing is performed on 1% and 99% percentile of continuous variables. The following data reports are based on the processed data results. In the end, a total of 588 listed firms were included, with a total of 4497 observations.

4.2. Variable and definition

4.2.1. Innovation quality

Academics often measure the innovation quality based on patent information. For example, Rong et al. (2017) use patent citations to measure the Chinese innovation quality. Fisch et al. (2017) evaluate the quality of patents by using the time span between the patent applications and its first citation. In order to ensure that the innovation quality covers as much patent information as possible, some scholars use principal component analysis (PCA) to synthesize the patents family scale, the breadth of patent applications, patent forward citations and backward citations into one indicator (Lanjouw & Schankerman, 2004; Schettino et al., 2013).

The above research on the firms' innovation quality by patent characteristics provides useful inspiration for this paper. However, considering that the CNIPA does not disclose citation data, the index of patent citation in China is only replaced by variable, which is easily accessible to data, thus it maybe subjective. Moreover, at the micro-firm level, it is difficult and laborious to identify each patent citation of each firm. Based on this, we draw on Boeing (2016) patent applications as an innovation indicator, and the application is closer to the time of invention, and it is also a summary of the current technology application and innovation. At the same time, according to Hu and Jefferson (2009), Bronzini and Piselli (2016), Hu et al. (2017) and Hou (2018), the patent application count (Patnet) is taken as the innovation quantity, and then the innovation quality from high to low is represented by invention patent application (Patenti), utility model patent application (Patentu) and design patent application (Patentd), respectively. The actual basis for this innovative quality classification comes from the classification of patents by the Chinese Patent Office. The Chinese patent system grants three types of patents: invention, utility, and design patents. Among them, invention patents are of the highest novelty and technological

inventiveness. To be granted, the application for an invention patents must meet the requirement of “novelty, inventiveness, and practical applicability.” In contrast, utility or design patents only require that a similar application has not previously been granted.

4.2.2. Market value

The purpose of filing a patent is not only to protect the firms’ business, but also to generate revenue from the commercialization process (Hsieh, 2013). Therefore, the innovation quality depends to a large extent on whether the patents applied can help firms gain competitive advantage in the market, and thus obtain excess profits. Scholars often use patents market value to regress the patents to determine the value of patents or the innovation quality (Bessen, 2009; Kim et al., 2018; Zhang et al., 2014), and believe that the higher the innovation quality, the higher the firms’ market value (Chen & Chang, 2010). This paper refers to the above research and uses Tobin’s Q as an indicator of the firms’ market value.

4.2.3. Control variable

Many studies have shown that firm’s characteristics are also important variables affecting the innovation quality. Based on this, we add six control variables, including firm size and its square term, age, asset-liability ratio, ownership structure and ownership concentration. The firm size is expressed as the firm’s year-end sales. The age (Ages) is expressed as the difference between 2016 and the year of establishment. The asset-liability ratio (Leverage) is expressed as total liabilities/total assets. SOE is expressed as a binary variable, if it contains state-owned shares, it is 1, otherwise it is 0. The degree of ownership concentration (COCEN) is expressed in the proportion of the first largest shareholder (%). The variable definitions are shown in Table 1.

4.3. Descriptive statistics

Based on the above variables, we will focus on the statistical information of variables such as innovation quantity (Patent), innovation quality (Patenti, Patentu and Patend) and market value. As can be seen from Table 2, the mean of patent applications of 588 listed firms in China in 2006-2016 was 22.811. The mean of utility model patent applications, invention patents and design patents are successively decreasing, which are 10.99, 10.434 and 1.387 respectively. This is also consistent with the performance of the maximum values of patents. It shows that the increase in the total number of patents of listed firms mainly comes from invention patents and new utility model patents. Further, this also indicates that firms are more inclined to apply for patents with substantial innovation or micro-innovation. Looking at the statistical information of market value, the mean of MV is 1.974, and the median is 1.414, indicating that at least half of the firms have market value of more than 1. From the case of the minimum and maximum values, they are 0.175 and 10.457, respectively, indicating that the market value of the firms may have a large degree of deviation.

Table 1. Variables and definition.

Variable classification	Variable symbol	Variable definitions
Dependent variable	LP	$\ln(\text{Patent} + 1)$
	LPi	$\ln(\text{Patenti} + 1)$
	LPu	$\ln(\text{Patentu} + 1)$
	LPd	$\ln(\text{Patentd} + 1)$
	MV	Tobin's Q
Control variable	Size	Year-end sales, take the natural logarithm
	Size ²	Squared item size
	Ages	2016 minus the firm's founding year, take the natural logarithm
	Leverage	Total liabilities/total assets
	SOE	The actual controller of the firm is the central and local SASAC, government agencies, state-owned firm, the variable is 1, otherwise 0
	COCEN	The proportion of the 1st largest shareholder (%), taken logarithm

Table 2. Descriptive statistics.

Variable	Obs	Mean	SD	Min	Max
Patent	4497	22.811	74.291	0	1276
Patenti	4497	10.434	35.664	0	684
Patentu	4497	10.99	42.87	0	842
Patentd	4497	1.387	9.619	0	263
MV	4497	1.974	1.86	0.175	10.457
Size	4497	21.562	1.472	18	25.338
Size ²	4497	467.084	64.408	324.013	642.034
Ages	4497	2.896	0.283	2.079	7.598
Leverage	4497	-0.838	0.604	-4.109	2.153
SOE	4497	0.522	0.5	0	1
COCEN	4497	3.502	0.474	2.142	4.377

5. Empirical result

5.1. Propensity score matching

Based on the introduction of the PSM-DID method mentioned above, this paper uses the nearest neighbor matching method in caliper to match the samples of “treatment group” and “control group” 1:1, in order to obtain the sub-samples for subsequent empirical analysis.

Table 3 shows the results of the Logit model estimation. As we can see all variables are significant at the 10% significance level, which indicating that China's CETS pilots are selected have certain non-randomness. It is worth noting that the coefficient of the firm size is significantly negative, but its squared term (Size²) has a positive impact on the implementation of the CETS. This is because the selection of pilot firms in the CETS needs to meet certain conditions. For example, Hubei Province only imposes firms with an annual energy consumption of more than 60,000 tons of standard coal into carbon trading, and these are mostly large-scale firms. In addition, the longer the business age (Ages), the easier it is to be selected as a CETS pilot firm, while the coefficient of ownership (SOE) and equity concentration (COCEN) is negative. It shows that private firms with scattered equity are more likely to be constrained by carbon emissions than state-owned firms with high concentration of ownership.

Table 3. PSM Logit regression results.

Variable	Coefficient	S.E.	Z value	P value
Size	-3.101***	0.545	-5.690	0.000
Size ²	0.0752***	0.012	6.040	0.000
Ages	0.301*	0.157	1.910	0.056
Leverage	-0.376***	0.072	-5.230	0.000
SOE	-0.256**	0.088	-2.900	0.004
COCEN	-0.332***	0.093	-3.570	0.000
_cons	30.23***	6.085	4.970	0.000

***p < 0.01, **p < 0.05, *p < 0.1.

Pseudo R²=0.0242, Wald Chi2 = 100.95, Log pseudolikelihood=-1991.9191.

In order to verify the reliability of the matching results, this paper conducts a balance hypothesis test on the control variables of the matched samples. Table 4 shows that before the trend score matching, expect for the average difference of Ages, the mean difference of other variables is significant at the 5% level, but after the matching operation, the mean difference of all variables between the “control group” and the “treatment group” is no longer significant. This indicates that the matched samples passed the balance test, thus ensuring the reliability of subsequent empirical results.

5.2. Induced effect test of environmental regulation

Firstly, the induced effect of environmental regulation model is regressed, and the results are shown in Table 5. Among them, (1a) - (1d) is the regression result of pre-matching sample DID, (2a) - (2d) is the regression result of post-matching PSM-DID. It should be noted that in order to eliminate the sequence correlation and heteroscedasticity, the obtained results are more robust, and all the following regressions are estimated by the FGLS method.

Compared with the regression results of DID and PSM-DID, the impact degree of CETS on firms' innovation is different, but the impact direction and significance are consistent, which indicates that the regression results are robust, preliminarily. From the coefficient size of CETS, the regression coefficients of PSM-DID are larger than the regression coefficients of DID. Except for SOE, the absolute values of other control variable coefficients are smaller than the regression coefficients of DID, and the saliency of all control variable coefficients is also reduced. In particular, the coefficient of COCEN is significantly changed from the original DID model to insignificant. It can be seen that the empirical results obtained by the PSM-DID regression method are more robust. Therefore, in the subsequent analysis, only the regression results of the PSM-DID method are explained.

In (2a) - (2d), the CETS has a positive impact on the patent applications count and three types of patents (invention patents, utility model patents, and design patents), but the impact on design patents are not significant. This shows that the CETS promotes technological innovation of firms and effectively induces firms to switch to high-quality innovation. The reason comes from two aspects. On the one hand, under strict environmental regulation, the original technology can no longer meet the needs

Table 4. PSM balance test.

Variable	Sample	Control group		Treatment group		Mean difference
		N	Mean	N	Mean	
Size	Unmatched	3738	21.5361	759	21.6891	-0.1529***
	Matched	731	21.7868	731	21.6522	0.135
Size ²	Unmatched	3738	465.83	759	473.2619	-7.4319***
	Matched	731	477.1242	731	471.3855	5.739
Ages	Unmatched	3738	2.8933	759	2.9102	-0.017
	Matched	731	2.8912	731	2.9072	-0.016
Leverage	Unmatched	3738	-0.8212	759	-0.9194	0.0982***
	Matched	731	-0.9164	731	-0.9169	0.001
SOE	Unmatched	3738	0.53	759	0.4835	0.0464**
	Matched	731	0.487	731	0.4788	0.008
COCEN	Unmatched	3738	3.5103	759	3.4603	0.0500***
	Matched	731	3.4888	731	3.4664	0.022

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

of energy conservation and emission mitigation. Under the burden of increasing “regulation costs”, firms have to carry out technological innovation (Hu et al., 2017). At the same time, because technological innovation has positive externalities, once technology is invented, it is difficult to exclude others from enjoying the benefits of technological innovation for free, so that firms will seek intellectual property protection by applying for patents (Dang & Motohashi, 2015). On the other hand, the CETS has greater flexibility as a market-based environmental regulation tool than command-control environmental regulation tools. Under the constraint of carbon emission, firms with higher technical level have stronger energy-saving and emission-reducing effects, and by selling excess carbon allowances, they will obtain additional profit, and thus firms are more willing to carry out higher-level innovation. This proves the research hypothesis H1: the CETS not only promotes the increase in the number of innovations, but also induces firms to turn to high-quality innovation.

In addition, the paper analyzes the impact of other control variables on the innovation quantity and the innovation quality. The size of the firm has a significant negative impact on the patents count, invention patents and utility model patents, but its secondary item Size² has played a significant role in promoting. It shows that the scale of the firm has a nonlinear impact on firm’s innovation. Although larger firm has more abundant funds, they can obtain high-quality patents through purchase and independent research and development (Gupeng & Xiangdong, 2012; Hu et al., 2017). At the same time, however, economies of scale have shown that only firm that exceed the threshold will have an amplification effect on firm’s innovation output (Tang, 2015). The business age (Ages) has a significant negative impact on the total number of patents, invention patents and utility model patents, while the impact on design patents is significantly positive. This may be because firm with long operating years have basically formed a market structure. The cost of original innovation and micro-innovation is huge. By attracting consumers through new designs that are aesthetically pleasing to the shape and pattern of products, the gains are even more considerable. The coefficient of asset-liability ratio (Leverage) is always negative, indicating that the asset-liability ratio is too high, which is not conducive to firm innovation.

Table 5. Environmental regulation induced effect regression results.

Variable	DID				PSM-DID			
	LP (1a)	LPI (1b)	LPU (1c)	LPD (1d)	LP (2a)	LPI (2b)	LPU (2c)	LPD (2d)
CEIS	0.488*** (7.02)	0.385*** (6.45)	0.477*** (7.61)	0.0112 (0.32)	0.799*** (6.26)	0.577*** (5.20)	0.709*** (6.02)	0.091 (1.42)
Size	-1.245*** (-4.03)	-1.173*** (-4.42)	-1.787*** (-6.41)	0.237 (1.50)	-0.985* (-1.84)	-0.996** (-2.14)	-1.157*** (-2.34)	0.38 (1.41)
Size ²	0.0404*** (5.69)	0.0366*** (6.00)	0.0505*** (7.87)	-0.00449 (-1.23)	0.0339** (2.77)	0.0325** (3.06)	0.0353** (3.13)	-0.00717 (-1.17)
Ages	-0.632*** (-8.26)	-0.526*** (-8.00)	-0.491*** (-7.11)	0.0991** (2.53)	-0.616*** (-4.92)	-0.612*** (-5.62)	-0.355*** (-3.07)	0.136** (2.15)
Leverage	-0.281*** (-7.61)	-0.227*** (-7.15)	-0.149*** (-4.47)	-0.0584** (-3.09)	-0.198** (-2.91)	-0.204*** (-3.45)	-0.0891 (-1.42)	-0.0361 (-1.06)
SOE	-0.219*** (-4.52)	-0.0727* (-1.75)	-0.229*** (-5.25)	-0.0811*** (-3.27)	-0.290** (-3.09)	-0.147* (-1.80)	-0.235*** (-2.71)	-0.0987** (-2.09)
COCEN	-0.102** (-2.22)	-0.0918** (-2.33)	-0.112** (-2.71)	0.0560** (2.39)	0.00278 (0.03)	-0.00533 (-0.08)	-0.0427 (-0.57)	0.0591 (1.44)
Constant	12.15*** (3.60)	11.42*** (3.94)	18.21*** (5.97)	-3.012* (-1.74)	9.02 (1.54)	9.366* (1.84)	10.95*** (2.02)	-4.917* (-1.67)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	4497	4497	4497	4497	1462	1462	1462	1462

The parenthesis are the t values, ***p < 0.01, **p < 0.05, *p < 0.1.

Table 6. Environmental regulation moderated effect regression results.

Variable	MV				
	(3)	(3a)	(3b)	(3c)	(3d)
CETS	0.620*** (4.14)				
LP _{t-1}		-0.0229 (-0.56)			
CETS*LP _{t-1}		0.0876* (1.90)			
LPi _{t-1}			-0.021 (-0.44)		
CETS*LPi _{t-1}			0.0933* (1.68)		
LPu _{t-1}				-0.0175 (-0.37)	
CETS*LPu _{t-1}				0.0332 (0.6)	
LPd _{t-1}					-0.0226 (-0.26)
CETS*LPd _{t-1}					0.201* (1.81)
Constant	76.42*** (11.11)	69.23*** (10.67)	69.13*** (10.65)	68.98*** (10.59)	69.21*** (10.70)
Province	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	1462	1350	1350	1350	1350

The parenthesis are the t values

***p < 0.01, **p < 0.05, *p < 0.1.

The coefficient of ownership (SOE) is negative, indicating that firm with state-owned shares significantly inhibited the application for patents by firm because Chinese state-owned shares have market power and are more used to maintain market power rather than technology innovation. It is worth noting that in the regression of the design patent (2d), except for the significant coefficients of Ages and SOE, the other variables are not significant. This may be because, as the most basic innovation, the patented design technology is relatively low (Boeing, 2016), and there is no need to submit reports and substantive review during the application process, which is more of autonomous behavior (Huang, 2016).

5.3. Moderated effect test of environmental regulation

It is generally believed that the innovation quality is not only reflected in the comparison of the number of patents, but more importantly, whether technological innovation can help firms gain competitive advantage and thus bring excess profits to firms. Based on this, this paper makes a regression analysis on the impact of various patents on market value. The specific results are shown in Table 6, in which (3) the impact of CETS on market value (3a) - (3d) the impact of patents and the interaction between patents and CETS on market value.

In the regression results (3), the CETS has a significant positive impact on market value. This shows that CETS can directly enhance the competitiveness or market value,

but this is not consistent with most studies on the impact of environmental regulation on the firms' competitiveness, or even a significant negative impact (Löschel et al., 2019; Zhao & Sun, 2016). This is because compared with the existing research on China's environmental regulation, this paper takes China's CETS as a research perspective and focuses on the impact of carbon emission constraints on the competitiveness of micro-firms. Moreover, it is generally believed that CETS is more flexible than command-control environmental regulation tools and can promote the firms' competitiveness. Although scholars have based on researches of EU ETS, and found that EU ETS cannot significantly enhance the firms' competitiveness. However, unlike the EU, on the one hand, China is at a time of economic low-carbon transformation, and the industrial structure is in a transitional transition from irrationality to rationality, and there is still huge potential for green development. On the other hand, China has a unified central government that makes the implementation of CETS policies more efficient and thus easily transformed into the thrust of firms' competitiveness.

It can be seen from (3a) - (3d) that in all regression results, The patent variables play a negative inhibitory role, but they are not significant at the 10% significance level. This shows that in the product market, patents applied by Chinese firms cannot be effectively converted into firms' competitiveness. Although China's total number of patent applications ranks first in the world (Huang, 2016), patents and technological innovations and the link between patents and firms' competitiveness are becoming weaker (Hu et al., 2017). Because firms are increasingly using patents as a marketing strategy rather than producing products (Thoma, 2013), these non-innovative patents create a waste of firms' resources, which is not conducive to the firms' competitiveness. In addition, during the "11th Five-Year Plan" period, China implemented a well-known "innovation-driven" strategy. Local government will increase subsidies for firms' patent applications due to their political achievements, resulting in a surge in the number of low-quality and invalid patent applications (Hu & Jefferson, 2009; Hu et al., 2017). Thus, the research hypothesis H2 is validated: the impact of high-quality innovation on firm competitiveness is uncertain, and may be positive or negative.

Interestingly, although the patents are not conducive to the improvement of firms' competitiveness, the interaction between the patent and the CETS has a positive effect on the firms' competitiveness, which means that the CETS can induce firms to apply for patents with higher market value. Because when firms are constrained by carbon emissions, the original technology is not enough to help firms offset the "regulation costs" brought about by environmental regulation. For this reason, firms have to switch to high-quality and energy-saving and emission reduction technology innovation. It should be emphasized that when there are no carbon emission constraints, this high-quality and energy-saving emission reduction technology will not only improve the firms' competitiveness, but also cause productivity loss due to excessive innovation (Hille & Möbius, 2019). In other words, the implementation of the CETS can accelerate the recognition of high-quality innovations by the market, so that firms can gain market power and thus bring excessive profits to the firms. This also verifies the research hypothesis H3: The CETS plays a positive role in moderating technological innovation and competitiveness, and can accelerate the recognition of high-quality innovation by the market, which in turn is conducive to competitiveness.

6. Heterogeneity and robustness test

6.1. Heterogeneity test

The above empirical results show that differences in firm ownership will also have an important impact on the innovation quality. Therefore, this paper divides the total sample into state-owned shares firms and non-state-owned shares firms by including whether the firm's equity includes state-owned shares.

As shown in Table 7, in the return of carbon emission trading to the quality of firm innovation, both state-owned and non-state-owned firms have promoted innovation quantity (LP) and innovation quality (LPi, LPu, and LPd), but the impact on the lowest quality innovation (LPd) is not significant at the 10% significance level. From the perspective of the coefficient size, in addition to the coefficient of the LPd, the coefficient of the sample group of the state-owned share firms is greater than that of the non-state-owned shares. This shows that compared with non-state-owned joint-stock firms, the CETS has a stronger inducing effect on the state-owned joint-stock firms turning to high-quality innovation.

Table 8 represents the Environmental regulation moderated effect regression results. It can be seen from (6) and (7) in the table that the CETS has a significant role in promoting the competitiveness of state-owned joint-stock firms and non-state-owned joint-stock firms, but the promotion effect on the competitiveness of non-state-owned firms is significantly greater. In the sample group of state-owned shares, only the design patent application and its interaction with the CETS have a significant impact on the market value, and the CETS can effectively regulate the adverse effects of low-quality patents on market value and promote the role. In the sample group of non-state-owned shares, innovation itself cannot promote the value of firms, but the interaction between technological innovation and CETS has a significant positive impact on market value. This shows that under the constraints of carbon emissions, the technological innovation of non-state-owned joint-stock firms is more easily accepted by the market, and thus the competitiveness of firms is improved.

Table 7. Heterogeneity test: environmental regulation induced effect regression results.

Variable	State-owned shares firms				Non-state-owned shares firms			
	LP (4a)	LPi (4b)	LPu (4c)	LPd (4d)	LP (5a)	LPi (5b)	LPu (5c)	LPd (5d)
CETS	0.843*** (5.18)	0.726*** (5.17)	0.749*** (5.02)	0.0333 (0.45)	0.540** (3.25)	0.298** (2.12)	0.507*** (3.37)	0.0422 (0.43)
Constant	20.99** (2.35)	21.54** (2.80)	18.05** (2.21)	-0.579 (-0.14)	-10.66 (-0.85)	-8.498 (-0.80)	7.449 (0.65)	-3.509 (-0.47)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	702	702	702	702	752	752	752	752

The parenthesis are the t values,
***p < 0.01, **p < 0.05, *p < 0.1.

Table 8. Heterogeneity test: environmental regulation moderated effect regression results.

Variable	State-owned shares firms					Non-state-owned shares firms				
	(6)	(6a)	(6b)	(6c)	(6d)	(7)	(7a)	(7b)	(7c)	(7d)
CEIS	0.248* (1.87)					1.077*** (4.46)				
LP _{t-1}		-0.0898** (-2.15)					-0.0706 (-0.91)			
CEIS*LP _{t-1}		0.0501 (1.10)					0.233** (2.69)			
LPI _{t-1}			-0.0482 (-1.00)					-0.0452 (-0.49)		
CEIS*LPI _{t-1}			0.0116 (0.21)					0.247** (2.38)		
LPU _{t-1}				-0.109** (-2.23)					-0.115 (-1.25)	
CEIS*LPU _{t-1}				0.0558 (1.01)					0.204* (1.88)	
LPd _{t-1}					-0.386** (-2.87)					-0.0353 (-0.21)
CEIS*LPd _{t-1}					0.477** (2.96)					0.296 (1.49)
Constant	100.9*** (13.86)	86.53*** (11.04)	85.82*** (10.92)	86.35*** (11.03)	87.34*** (11.16)	73.89*** (4.03)	85.10*** (4.62)	84.80*** (4.60)	84.70*** (4.57)	84.16*** (4.55)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	702	666	666	666	666	752	666	666	666	666

The parenthesis are the t values,
 ***p < 0.01, **p < 0.05, *p < 0.1.

Table 9. OLS robust standard error regression results.

Variable	LP (8a)	Lpi (8b)	Lpu (8c)	LPd (8d)	MV				
					(9)	(9a)	(9b)	(9c)	(9d)
CETS	0.799*** (5.94)	0.577*** (4.96)	0.709*** (6.11)	0.0910* (1.72)	0.620*** (4.35)				
LP _{t-1}						-0.0627* (-1.80)			
CETS*LP _{t-1}						0.104** (2.68)			
LPI _{t-1}							-0.0519 (-1.29)		
CETS*LPI _{t-1}							0.107** (2.25)		
LPU _{t-1}								-0.0651* (-1.73)	
CETS*LPU _{t-1}								0.0568 (1.28)	
LPd _{t-1}									0.0456 (0.67)
CETS*LPd _{t-1}									0.149* (1.74)
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1462	1462	1462	1462	1462	1350	1350	1350	1350
R ²	0.297	0.293	0.291	0.077	0.445	0.439	0.438	0.437	0.439

The parenthesis are the t values,
 ***p < 0.01, **p < 0.05, *p < 0.1.

6.2. Robustness test

1. OLS robust standard error estimation

In order to eliminate missing variables that would vary due to individual differences, this paper based on the samples obtained by the aforementioned PSM method, re-evaluated using OLS robust standard error, the results are shown in Table 9. Compared with the above FGLS estimation results, in the OLS estimation results, except for the CETS, the design patent application has not changed significantly from the original to the significant, and the other variable coefficients have not changed significantly. This suggests that the choice of estimation method will have some interference to the empirical results, but it is very limited.

2. Optimal propensity score matching method

The above empirical samples are obtained by using the nearest neighbor matching method within the caliper range, but the subsamples obtained by the nearest neighbor matching are related to the ordering of the processing group samples in the original sample. That is, the ordering of the processing group samples in the original sample changes, and the obtained sub-samples will also change, which will affect the empirical results. In view of this, this paper is based on R software, using the optimal (Optimal matching method), and the original sample is subjected to propensity score matching in a ratio of 1:2, and then the regression analysis is performed on the matched subsamples using stata12.0. The results are shown in Table 10. Compared with the results obtained before, the robustness test results showed no significant

Table 10. Optimal propensity score matching method and OLS regression results.

Variable	MV									
	LP (10a)	LPI (10b)	LPu (10c)	LPd (10d)	(11)	(11a)	(11b)	(11c)	(11d)	
CETS	0.536*** (6.43)	0.407*** (5.67)	0.538*** (7.02)	0.0487 (1.13)	0.547*** (5.57)					
LP _{t-1}						-0.0226 (-0.80)				
CETS*LP _{t-1}						0.0687** (2.03)				
LPI _{t-1}							-0.0143 (-0.44)			
CETS*LPI _{t-1}							0.0719* (1.76)			
LPu _{t-1}								-0.0563* (-1.83)		
CETS*LPu _{t-1}								0.0442 (1.12)		
LPd _{t-1}									0.0935 (1.63)	
CETS*LPd _{t-1}									0.116 (1.46)	
Constant	13.10*** (3.46)	10.81*** (3.32)	19.85*** (5.72)	-2.449 (-1.25)	61.01*** (13.67)	69.93*** (12.22)	69.76*** (12.18)	70.33*** (12.27)	70.52*** (12.33)	
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3036	3036	3036	3036	3036	2100	2100	2100	2100	2100
R ²	0.306	0.303	0.304	0.061	0.421	0.45	0.45	0.45	0.45	0.452

The parenthesis are the t values,
 ***p < 0.01, **p < 0.05, *p < 0.1.

change in the significance and influence direction except for the slight change of the regression coefficient. It can be seen that although the choice of the preference score matching method has caused some interference to the empirical results, the degree is limited, indicating that the empirical results in this paper are robust.

In addition, this paper also uses the following two methods for robustness testing. Firstly, we delete the samples with zero patent application, perform the nearest neighbor matching in the caliper again, and then repeat the steps of Tables 3–6, and obtain a total of 1154 samples. The empirical results obtained are still consistent with those in Tables 5–6, see Table 6 in the appendix, Supplementary material. Secondly, the results obtained by replacing Tobin's Q with Operating Margin are still robust, as shown in Table 7 of the appendix, Supplementary material.

7. Discussion and conclusion

Based on the existing research on the “Porter Hypothesis”, this paper divides firms' innovation into high-to-low innovation quality, according to the firms' patent application category (invention patent, utility model patent and design patent), and based on theoretical analysis to propose research hypotheses. Finally, the research hypothesis was tested using the 2006–2016 China A-share listed firm panel data and the PSM-DID model. We get the following conclusions.

The CETS has a positive effect on the innovation quantity and the innovation quality. In the baseline model, the CETS has a positive impact on the patents count and three types of patents (invention patents, utility model patents, and design patents), but the impact on design patents is not significant. It shows that the CETS can induce high-quality innovation of firms, and thus answer the basic question of whether the CETS can force firms to switch to high-quality innovation. The reason is that under the constraint of carbon emission, the original technology has been unable to meet the requirements of energy conservation and emission reduction. In order to alleviate the increasing burden of “regulation cost”, firms will carry out technological innovation (Hu et al., 2017). However, from the perspective of the degree of influence, the impact of the CETS on the total number of patents, utility model patents and invention patents are decreasing. This shows that, for the moment, Chinese firms have not really got rid of the traditional innovation strategy of patent-based quantitative. The reasons are mainly from two aspects. On the one hand, considering the technology spillover effect, compared with the original technology innovation, appropriate application technology innovation within the existing technology framework can not only avoid the uncertainty risks brought by the original technology innovation, but also enable firms to enjoy the “innovation compensation” brought by the application innovation faster. In addition, giving full play to the economies of scale of firms and increasing the reform of state-owned firms are also important driving forces for improving the innovation quality.

Patents cannot improve the firms' competitiveness, but the CETS can accelerate the market identification of innovation. Firstly, the CETS has a significant positive impact on market value indicating that the CETS, as a more flexible environmental regulation tool, can promote the firms' competitiveness, thus also verifying the narrow version

“Porter Hypothesis”. It is generally believed that market-based environmental regulatory tools give firms greater flexibility to reduce pollution (Johnstone et al., 2017; Ren et al., 2018; Tang, 2015). In the carbon emission market, firms can obtain excess returns by selling excess carbon allowances, or they can reduce penalties and increase production income by buying carbon allowances. Secondly, no matter how the innovation quality cannot improve the firms’ competitiveness, it shows that most patents applied by Chinese firms cannot be effectively translated into real profits. As mentioned above, It is generally believed that the quality of innovation is positively correlated with corporate value, but high-quality innovation may not necessarily bring high returns to the firm due to market failures (Lanjouw & Schankerman, 2004). Especially when the market environment has not changed significantly, if the technological innovation of the firms is too advanced, it will not only not be recognized by the market, but also cause the loss of competitiveness due to the waste of resources (Hsieh, 2013). In other words, high-quality innovation cannot be automatically recognized by the market. Finally, the interaction between patents and CETS has a positive role in promoting the firms’ competitiveness. This means that CETS can induce firms to apply for patents with high market value. In other words, CETS can accelerate the market’s identification of innovation. This is because, on the one hand, technological innovation can reduce the cost burden brought by carbon emission constraints; on the other hand, the implementation of CETS has changed the market environment that did not pay attention to environmental protection in the past, so that high-quality innovation can be recognized and accepted by the market. Thus, it answers the question of whether the firms’ strategy of switching to high-quality innovation can enhance the competitiveness.

Differences in firm ownership will also have a greater impact on the inducing effect and moderating effect of CETS. The CETS has a significant role in promoting the innovation quantity (patent application count) and the innovation quality (invention patent application and utility model patent application) for both state-owned and non-state-owned firms, but it has a stronger inducement for state-owned joint-stock firms to turn to high-quality innovation. From the perspective of the impact of CETS and technological innovation on firm competitiveness, the CETS has a significant role in promoting the competitiveness of state-owned joint-stock firms and non-state-owned joint-stock firms, but it has a stronger role in promoting the competitiveness of non-state-owned firms.

This paper may have some limitations are as followed. Firstly, on the sample selection. This paper only uses A-share listed firms as a research sample. Although it helps to obtain sufficient and reliable data and has a strong persuasive force, it may cause some sample selection biased because non-listed firms are not considered. In the future, you can consider expanding the sample size or using a sample of non-listed firms to conduct related research. Secondly, on the identification of innovation quality. This paper only classifies the innovation quality based on the type of patent application. Although it can also reflect the quality of innovation to a certain extent, it is still not comprehensive. In the future, we will consider collecting more detailed patent information to deepen subsequent research. Thirdly, on firm’s competitiveness. This paper mainly uses Tobin’s Q as an indicator of the firms’ market competitiveness, and

also uses operating margin as a substitute indicator in the robustness test. To a certain extent, the robustness of the empirical results is guaranteed, but it is still insufficient for the firms' competitiveness. In the future, the impact of CETS on firms' productivity can be further considered.

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Author contributions

Jiangfeng Hu and Xiding Chen conceived and designed the research question. Jiangfeng Hu constructed the models, analyzed the optimal solutions, and wrote the paper. Qinghua Huang reviewed and edited the manuscript. All authors read and approved the manuscript.

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References

- Acemoglu, D., Aghion, P., Bursztyn, L., & Hémous, D. (2012). The environment and directed technical change. *The American Economic Review*, 102(1), 131–166. doi: [10.1257/aer.102.1.131](https://doi.org/10.1257/aer.102.1.131)
- Ambec, S., Cohen, M. A., Elgie, S., & Lanoie, P. (2013). The porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Review of Environmental Economics and Policy*, 7(1), 2–22. doi: [10.1093/reep/res016](https://doi.org/10.1093/reep/res016)
- Anderson, B. J., Convery, F., & Maria, C. D. (2010). Technological change and the EU ETS: The case of Ireland. *Ssrn Electronic Journal*, 216(1-2), 233–238. doi: [10.1016/j.respol.2014.10.014](https://doi.org/10.1016/j.respol.2014.10.014)
- Bel, G., & Joseph, S. (2018). Policy stringency under the European Union Emission trading system and its impact on technological change in the energy sector. *Energy Policy*, 117, 434–444. doi: [10.1016/j.enpol.2018.03.041](https://doi.org/10.1016/j.enpol.2018.03.041)
- Bergek, A., & Berggren, C. (2014). The impact of environmental policy instruments on innovation: A review of energy and automotive industry studies. *Ecological Economics*, 106, 112–123. doi: [10.1016/j.ecolecon.2014.07.016](https://doi.org/10.1016/j.ecolecon.2014.07.016)

- Bessen, J. (2009). Estimates of patent rents from firm market value. *Research Policy*, 38(10), 1604–1616. doi: [10.1016/j.respol.2009.09.014](https://doi.org/10.1016/j.respol.2009.09.014)
- Boeing, P. (2016). The allocation and effectiveness of China's R&D subsidies - Evidence from listed firms. *Research Policy*, 45(9), 1774–1789. doi: [10.1016/j.respol.2016.05.007](https://doi.org/10.1016/j.respol.2016.05.007).
- Boeing, P., & Mueller, E. (2016). Measuring patent quality in cross-country comparison. *Economics Letters*, 149, 145–147. doi: [10.1016/j.econlet.2016.10.039](https://doi.org/10.1016/j.econlet.2016.10.039)
- Borghesi, S., Cainelli, G., & Mazzanti, M. (2015). Linking emission trading to environmental innovation: Evidence from the Italian manufacturing industry. *Research Policy*, 44(3), 669–683. doi: [10.1016/j.respol.2014.10.014](https://doi.org/10.1016/j.respol.2014.10.014)
- Bronzini, R., & Piselli, P. (2016). The impact of R&D subsidies on firm innovation. *Research Policy*, 45(2), 442–457. doi: [10.1016/j.respol.2015.10.008](https://doi.org/10.1016/j.respol.2015.10.008).
- Calel, R., & Dechezleprêtre, A. (2016). Environmental policy and directed technological change: Evidence from the European carbon market. *Review of Economics and Statistics*, 98(1), 173–191. doi: [10.1162/REST_a_00470](https://doi.org/10.1162/REST_a_00470)
- Chen, Y. S., & Chang, K. C. (2010). The nonlinear nature of the relationships between the patent traits and corporate performance. *Scientometrics*, 82(1), 201–210. doi: [10.1007/s11192-009-0101-3](https://doi.org/10.1007/s11192-009-0101-3)
- Dang, J., & Motohashi, K. (2015). Patent statistics: A good indicator for innovation in China? Patent subsidy program impacts on patent quality. *China Economic Review*, 35, 137–155. doi: [10.1016/j.chieco.2015.03.012](https://doi.org/10.1016/j.chieco.2015.03.012)
- Fang, G., Tian, L., Liu, M., Fu, M., & Sun, M. (2018). How to optimize the development of carbon trading in China—Enlightenment from evolution rules of the EU carbon price. *Applied Energy*, 211, 1039–1049. doi: [10.1016/j.apenergy.2017.12.001](https://doi.org/10.1016/j.apenergy.2017.12.001)
- Fisch, C., Sandner, P., & Regner, L. (2017). The value of Chinese patents: An empirical investigation of citation lags. *China Economic Review*, 45, 22–34. doi: [10.1016/j.chieco.2017.05.011](https://doi.org/10.1016/j.chieco.2017.05.011)
- Ghosal, V., Stephan, A., & Weiss, J. (2014). Decentralized regulation, environmental efficiency and productivity. *Working Paper*, 5(6), 4200–4248.
- Gilli, M., Mancinelli, S., & Mazzanti, M. (2014). Innovation complementarity and environmental productivity effects: Reality or delusion? Evidence from the EU. *Ecological Economics*, 103, 56–67. doi: [10.1016/j.ecolecon.2014.04.004](https://doi.org/10.1016/j.ecolecon.2014.04.004)
- Gray, W. B., & Shadbegian, R. J. (1998). Environmental regulation, investment timing, and technology choice. *The Journal of Industrial Economics*, 46(2), 235–256. doi: [10.1111/1467-6451.00070](https://doi.org/10.1111/1467-6451.00070)
- Guo, Y., Xia, X., Zhang, S., & Zhang, D. (2018). Environmental regulation, government R&D funding and green technology innovation: evidence from China provincial data. *Sustainability*, 10(4), 940. doi: [10.3390/su10040940](https://doi.org/10.3390/su10040940).
- Gupeng, Z., & Xiangdong, C. (2012). The value of invention patents in China: Country origin and technology field differences. *China Economic Review*, 23(2), 357–370. doi: [10.1016/j.chieco.2012.02.002](https://doi.org/10.1016/j.chieco.2012.02.002)
- Hall, B., Jaffe, A., & Trajtenberg, M. (2005). Market value and patent citations. *RAND Journal of Economics*, 36(1), 16–38. doi: [10.1007/s11127-005-3550-0](https://doi.org/10.1007/s11127-005-3550-0)
- Hille, E., & Möbius, P. (2019). Environmental policy, innovation, and productivity growth: Controlling the effects of regulation and endogeneity. *Environmental and Resource Economics*, 73(4), 1315–1314. doi: [10.1007/s10640-018-0300-6](https://doi.org/10.1007/s10640-018-0300-6)
- Hou, J. (2018). Does the pay gap in the top management team incent enterprise innovation?—Based on property rights and financing constraints. *American Journal of Industrial and Business Management*, 08(05), 1290–1307. doi: [10.4236/ajibm.2018.85088](https://doi.org/10.4236/ajibm.2018.85088)
- Hsieh, C.-H. (2013). Patent value assessment and commercialization strategy. *Technological Forecasting and Social Change*, 80(2), 307–319. doi: [10.1016/j.techfore.2012.09.014](https://doi.org/10.1016/j.techfore.2012.09.014)
- Hu, A. G., & Jefferson, G. H. (2009). A great wall of patents: What is behind China's recent patent explosion? *Journal of Development Economics*, 90(1), 57–68. doi: [10.1016/j.jdevco.2008.11.004](https://doi.org/10.1016/j.jdevco.2008.11.004)

- Hu, A. G. Z., Zhang, P., & Zhao, L. (2017). China as number one? Evidence from China's most recent patenting surge. *Journal of Development Economics*, 124, 107–119. doi: [10.1016/j.jdeveco.2016.09.004](https://doi.org/10.1016/j.jdeveco.2016.09.004)
- Hu, D., Wang, Y., Huang, J., & Huang, H. (2017). How do different innovation forms mediate the relationship between environmental regulation and performance? *Journal of Cleaner Production*, 161, 466–476. doi: [10.1016/j.jclepro.2017.05.152](https://doi.org/10.1016/j.jclepro.2017.05.152)
- Huang, C. (2016). Estimates of the value of patent rights in China. In Liu, K.-C., Racherla, U.S. (Eds.), *Innovation and IPRs in China and India: Myths, realities and opportunities* (pp. 181–209). Springer.
- Johnstone, N., Managi, S., Rodríguez, M. C., Hašič, I., Fujii, H., & Souchier, M. (2017). Environmental policy design, innovation and efficiency gains in electricity generation. *Energy Economics*, 63, 106–115. doi: [10.1016/j.eneco.2017.01.014](https://doi.org/10.1016/j.eneco.2017.01.014)
- Keohane, N., Petsonk, A., & Hanafi, A. (2017). Toward a club of carbon markets. *Climatic Change*, 144(1), 81–95. doi: [10.1007/s10584-015-1506-z](https://doi.org/10.1007/s10584-015-1506-z)
- Kim, D., Kim, N., & Kim, W. (2018). The effect of patent protection on firms' market value: The case of the renewable energy sector. *Renewable and Sustainable Energy Reviews*, 82, 4309–4319. doi: [10.1016/j.rser.2017.08.001](https://doi.org/10.1016/j.rser.2017.08.001)
- Löschel, A., Lutz, B. J., & Managi, S. (2019). The impacts of the EU ETS on efficiency and economic performance – An empirical analyses for German manufacturing firms. *Resource and Energy Economics*, 56, 71–95. doi: [10.1016/j.reseneeco.2018.03.001](https://doi.org/10.1016/j.reseneeco.2018.03.001)
- Lanjouw, J. O., & Schankerman, M. (2004). Patent quality and research productivity: Measuring innovation with multiple indicators. *The Economic Journal*, 114(495), 441–465. doi: [10.1111/j.1468-0297.2004.00216.x](https://doi.org/10.1111/j.1468-0297.2004.00216.x)
- Liu, L., Chen, C., Zhao, Y., & Zhao, E. (2015). China's carbon-emissions trading: Overview, challenges and future. *Renewable and Sustainable Energy Reviews*, 49, 254–266. doi: [10.1016/j.rser.2015.04.076](https://doi.org/10.1016/j.rser.2015.04.076)
- Nesta, L., Vona, F., & Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management*, 67(3), 396–411. doi: [10.1016/j.jeem.2014.01.001](https://doi.org/10.1016/j.jeem.2014.01.001)
- Porter, M. E., & Linde, Cvd. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, 9(4), 97–118. doi: [10.1257/jep.9.4.97](https://doi.org/10.1257/jep.9.4.97)
- Ren, S., Li, X., Yuan, B., Li, D., & Chen, X. (2018). The effects of three types of environmental regulation on eco-efficiency: A cross-region analysis in China. *Journal of Cleaner Production*, 173, 245–255. doi: [10.1016/j.jclepro.2016.08.113](https://doi.org/10.1016/j.jclepro.2016.08.113)
- Rexhäuser, S., & Rammer, C. (2014). Environmental innovations and firm profitability: Unmasking the porter hypothesis. *Environmental and Resource Economics*, 57(1), 145–167. doi: [10.1007/s10640-013-9671-x](https://doi.org/10.1007/s10640-013-9671-x)
- Rong, Z., Wu, X., & Boeing, P. (2017). The effect of institutional ownership on firm innovation: Evidence from Chinese listed firms. *Research Policy*, 46(9), 1533–1551. doi: [10.1016/j.respol.2017.05.013](https://doi.org/10.1016/j.respol.2017.05.013)
- Rubashkina, Y., Galeotti, M., & Verdolini, E. (2015). Environmental regulation and competitiveness: Empirical evidence on the Porter Hypothesis from European manufacturing sectors. *Energy Policy*, 83, 288–300. doi: [10.1016/j.enpol.2015.02.014](https://doi.org/10.1016/j.enpol.2015.02.014)
- Rubin, R. (1985). The prospects for clinical psychoneuroendocrinology: has the curtain been drawn across the neuroendocrine window? *Psychological Medicine*, 15(3), 451–454. doi: [10.1017/S0033291700031329](https://doi.org/10.1017/S0033291700031329)
- Schettino, F., Sterlacchini, A., & Venturini, F. (2013). Inventive productivity and patent quality: Evidence from Italian inventors. *Journal of Policy Modeling*, 35(6), 1043–1056. doi: [10.1016/j.jpolmod.2013.02.008](https://doi.org/10.1016/j.jpolmod.2013.02.008)
- Song, X., Lu, Y., Shen, L., & Shi, X. (2018). Will China's building sector participate in emission trading system? Insights from modelling an owner's optimal carbon reduction strategies. *Energy Policy*, 118, 232–244. doi: [10.1016/j.enpol.2018.03.075](https://doi.org/10.1016/j.enpol.2018.03.075)
- Tang, R. (2015). Environmental regulation and firm innovation: Evidence from China. *Working Paper*, 1–40.

- Thoma, G. (2013). Quality and value of chinese patenting: An international perspective. *Seoul Journal of Economics*, 26(1), 33–72.
- Tollefson, J. (2016). China's carbon emissions could peak sooner than forecast. *Nature*, 531(7595), 425–426. doi: [10.1038/531425a](https://doi.org/10.1038/531425a)
- Triguero, A., Moreno-Mondéjar, L., & Davia, M. A. (2013). Drivers of different types of eco-innovation in European SMEs. *Ecological Economics*, 92(92), 25–33. doi: [10.1016/j.ecolecon.2013.04.009](https://doi.org/10.1016/j.ecolecon.2013.04.009)
- Wang, X., & Lin, B. (2016). How to reduce CO 2 emissions in China's iron and steel industry. *Renewable and Sustainable Energy Reviews*, 57, 1496–1505. doi: [10.1016/j.rser.2015.12.131](https://doi.org/10.1016/j.rser.2015.12.131)
- Weng, Q., Xu, H., & Kazmerski, L. (2018). A review of China's carbon trading market. *Renewable and Sustainable Energy Reviews*, 91(8), 613–619. doi: [10.1016/j.rser.2018.04.026](https://doi.org/10.1016/j.rser.2018.04.026)
- Xu, W., Wan, B., Zhu, T., & Shao, M. (2016). CO 2 emissions from China's iron and steel industry. *Journal of Cleaner Production*, 139(DEC), 1504–1511. doi: [10.1016/j.jclepro.2016.08.107](https://doi.org/10.1016/j.jclepro.2016.08.107)
- Yuan, B., Ren, S., & Chen, X. (2017). Can environmental regulation promote the coordinated development of economy and environment in China's manufacturing industry?—A panel data analysis of 28 sub-sectors. *Journal of Cleaner Production*, 149, 11–24. doi: [10.1016/j.jclepro.2017.02.065](https://doi.org/10.1016/j.jclepro.2017.02.065)
- Yuan, B., & Xiang, Q. (2018). Environmental regulation, industrial innovation and green development of Chinese manufacturing: Based on an extended CDM model. *Journal of Cleaner Production*, 176(5), 895–908. doi: [10.1016/j.jclepro.2017.12.034](https://doi.org/10.1016/j.jclepro.2017.12.034)
- Zhang, G., Lv, X., & Zhou, J. (2014). Private value of patent right and patent infringement: An empirical study based on patent renewal data of China. *China Economic Review*, 28, 37–54. doi: [10.1016/j.chieco.2013.11.004](https://doi.org/10.1016/j.chieco.2013.11.004)
- Zhang, X., Zhao, X., Jiang, Z., & Shao, S. (2017). How to achieve the 2030 CO 2 emission-reduction targets for China's industrial sector: Retrospective decomposition and prospective trajectories. *Global Environmental Change*, 44(5), 83–97. doi: [10.1016/j.gloenvcha.2017.03.003](https://doi.org/10.1016/j.gloenvcha.2017.03.003)
- Zhang, Y. J., Peng, Y. L., Ma, C. Q., & Shen, B. (2017). Can environmental innovation facilitate carbon emissions reduction? Evidence from China. *Energy Policy*, 100, 18–28. doi: [10.1016/j.enpol.2016.10.005](https://doi.org/10.1016/j.enpol.2016.10.005)
- Zhao, X., & Sun, B. (2016). The influence of Chinese environmental regulation on corporation innovation and competitiveness. *Journal of Cleaner Production*, 112, 1528–1536. doi: [10.1016/j.jclepro.2015.05.029](https://doi.org/10.1016/j.jclepro.2015.05.029)