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The Impact of Market and Non-Market-Based Environmental Policy Instruments on Firms' Sustainable Technological Innovation: Evidence from Chinese Firms

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Abstract: A firm's sustainable technological innovation (STI) is an important strategy to cope with the global challenges of the climate emergency and resource constraints. To encourage firms to pursue sustainable innovation, the government put its efforts into designing a proper environmental policy (EP). According to Porter's hypothesis, a well-designed and flexible EP will advance the pace of a firm's innovation. This paper argues that a flexible EP portfolio combining market and non-market-based EP instruments may affect a firm's STI. Market-based EP instruments are cost-effective and consistent from a long-term view, whereas non-market-based EP instruments are more forceful and effective in the short term. Hence, these two kinds of EP instruments could complement each other. Furthermore, technical executives in top management teams will moderate the relationships between EP instruments and firms' STI. Data analysis results of 618 Chinese public firms, who constantly participated in R&D activities during 2015–2019, supported these hypotheses. Contributions to EP and firm innovation theory, as well as suggestions for policymakers and firms' top management teams, are discussed.

Keywords: environmental policy; policy mix; sustainable technological innovation; technical executives

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1. Introduction

High energy consumption and high emissions from industrialization pose an increasing threat to pollution and global warming. A firm's sustainable technological innovation (STI) is an important strategy to cope with the global challenges of pollution and resource constraints [1]. The challenge of approaching a firm's sustainability relies on the firm's STI [2,3]. Unlike technological innovation (TI), which merely focuses on upgrades and technological advances, STI refers to constantly gaining advantages through technological innovation and commercialization while respecting the environment [4,5]. This is in contrast to some research that argued that green patent numbers indicate STI performance. That is only a part of STI, which requires incessant R&D inputs and constantly profiting from the patentability and commercialization of the outputs while respecting the environment. STI falls under the umbrella of sustainable innovation (SI), which is a broader conception including making deliberate improvements to a firm's products, services, or business operations to produce long-term social and environmental advantages while generating financial success [6]. Thus, these long-term goals should be based on a proper EP framework that seeks to balance solving environmental issues and to boost technological innovation [7–9]. Previous research might discuss various utilized EP instruments and new tools [10,11]. However, the harmonization mechanism of non-market-based and market-based EP tools is underexplored. Moreover, abundant research has been expanded in discussing the relationship between EP instruments and SI from the viewpoint of sustainable green technological innovation (SGTI) and sustainable green business model innovation. Nevertheless, it is an undeveloped research question about how a flexible EP portfolio affects the STI, specifically keeping a watchful eye on the balance of constant technological progress efficiency with sustainable green technology outputs.

Market-based and command-and-control policy instruments are the two most popular EP instruments to encourage firms' STI. Market-based policy instruments, such as environmental taxation and emission trading, are designed to fit the market mechanism. In contrast, command-and-control policy instruments are non-market-based policy instruments, such as environmental protection investment (EPI) and pollution fines. The OECD (2013) has been promoting the use of market-based instruments for many years, including taxes and emission trading systems. These instruments are regarded as the cheapest way for societies to reduce emissions. In 2019, EU environmental tax revenue amounted to EUR 330.6 billion, accounting for 5.9% of total government revenue from taxes and social contributions.

Similarly, the United States stopped its command-and-control regulatory approach in which the government requires individual plants to install specific control technologies to reduce pollution, regardless of varying costs of controls among the plants. Instead, in 1990, the United States passed the Clean Air Act Amendments and followed a market-based EP approach, known as cap-and-trade or "allowance trading", to address the acid rain problem [12]. According to these practices, countries prefer market-based EP instruments.

The Chinese government has pursued command-and-control regulation for several decades. The Chinese government has intensively used command-and-control regulation to prevent firms from overexploiting natural resources and maintain sustainable development. For example, firms' business costs include money invested in afforestation and penalty fees by the local government. The Beijing government regulated peremptory afforested areas of plants based on different industries in 1990, specifically requiring factories that produce toxic and harmful gas to accomplish afforestation no less than 40% of their land. In 2003, the China State Council centralized and reinforced administrative power for the environmental penalty, including an increased penalty for illegal storage of coal, transportation, loading, or storage of toxic and hazardous gases or dust-emitting substances. A new environmental protection law in 2018 grants the local government the right to shut down enterprises whose pollutants or emissions exceed the standard.

In recent years, however, single use of a non-market-based EP tool has proved to be unsustainable and only effective in the short term [13,14]. Countries with commitments under the Kyoto Protocol to limit or reduce greenhouse gas emissions must meet their targets primarily through national measures. As an additional means of meeting these targets, the Kyoto Protocol introduced three market-based mechanisms, thereby creating what is now known as the carbon market. These mechanisms help countries that have made Kyoto commitments meet their targets by reducing emissions or reducing carbon from the atmosphere in other countries cost-effectively. This approach encourages the private sector and emerging countries to contribute to emission reduction efforts. The Kyoto Protocol Mechanism created an international framework for market-based regulation and stimulated the development of greenhouse gas emission trading mechanisms at the national and international levels. The Chinese government has been encouraged to adopt market-based EP instruments, and China is opening up a new era of environmental protection. In 2013, the first Chinese carbon emission trading platform was launched in Shenzhen, marking a crucial step in developing China's emission trading system. In 2018, the Chinese government canceled the pollution fee, a command-and-control EP tool, and replaced it with environmental taxation, a marked-based EP tool. The startup of China's unified carbon emissions trading market in July 2021, covering more than 4 billion tons of emissions, has made it the world's largest carbon market.

Marked-based and non-marked-based EP instruments are simultaneously used in China, which raises important research questions: Will the mixed EP instrument lead to policy conflict and crowding out? Or, will the two kinds of EP instruments complement each other and generate a friendly environment that stimulates firms' STI? Will technical executives react to governments' EP instruments [15,16]? Only some studies have addressed these research issues. The ability to answer these questions is particularly important because it will help government more effectively apply EP instruments to improve firms' STI and benefit society in sustainable innovation. Thus, we filled this gap by first exploring the single and co-effects of market-based and non-market-based EP instruments on STI. Then, we empirically analyzed the separate and interactive effect of the two kinds of EP instruments on Chinese firms' STI. We selected environmental protection tax (EPT) and EPI to represent market-based and non-market-based EP instruments and to assess the effects of advantages and disadvantages.

This paper is structured as follows. Section 2 reviews the literature on EP instruments and firms' STI. Then, we offer two hypotheses, proposing that the direct influence of EPT and EPI on firms' STI may be positive and negative, respectively. Executives with technological backgrounds could strengthen EPT's positive effect and lessen EPI's negative impact. Moreover, mixed-use EPT and EPI instruments should improve firms' STI. Section 3 reports the samples and data collecting process and data analysis strategy. Section 4 presents the empirical results, and Section 5 provides a theoretical discussion and practical suggestions.

2. Literature Review and Hypotheses

2.1. The Framework of EP Instruments and Innovation

2.1.1. Stepping to Embrace Market-Based EP Instruments from EPT Reform

EP instruments are designed to prevent or reduce the harmful impacts of human activities on ecosystems. Thus, the ability to encourage firm innovation is a follow-up objective of EP's primary goal [15] (i.e., reduce pollutants). The function of EP to stimulate innovation was first observed by Porter [7]. Porter and Van der Linde [8] found that market-based regulation is more flexible and better for facilitating technological innovation. Market-based EP tools focus on the results of enterprises rather than intervening in their processes or directly controlling the pollution of enterprises [17]. Therefore, they will not disrupt the market operation mechanism [18,19].

Moreover, market-based EP instruments are low-cost and easy to apply. For example, in the case of EPT, the EPT rule (i.e., more emissions, more charges; fewer emissions, fewer charges) creates room for regulators to adjust the levies in the later year according to firms' marginal costs of annual pollution. Similarly, according to their business strategies, firms can decide to manufacture less to decrease their emission or maintain their manufacturing speed at the cost of the EPT.

In addition, market-based environmental regulation policies usually have reliable consistency. For example, in the case of an EPT, the change of the levy standard needs to be decided by the Standing Committee of the Provincial People's Congress rather than the local government. Therefore, the policy is less likely to be changed by the government's preference based on the economic contribution of enterprises to the local area.

Conversely, governments' command-and-control regulations have been found to be less effective from a long-term view [20], such as EPI. Additional cost enterprises pay to reduce pollution, which creates more social benefits than economic benefits for enterprises [21]. It may also decrease R&D inventiveness for upgrading technology based on a long-term view. One primary characteristic of non-market-based EP instruments is to force enterprises to bear the cost burden of public pollution control that is not directly caused by these enterprises [22]. For example, public firms constantly invest money to support public afforestation, decrease pollution, and mandate governance wastewater abatement [23].

Before implementing the Environmental Protection Tax Law, China had a long-standing sewage charging system. The implementation of the emission charging system suffers from the disadvantages of low charging standards, many administrative interventions, insufficient rigidity of enforcement, non-standard rates, and lack of standardization, which have affected the effectiveness of its role in pollution control and emission reduction [24,25]. External factors such as administrative intervention and legal circumstances inevitably affect the emission charging system and are not mandatory, enforceable, and supervisory enough. For example, some local governments are oriented to economic growth, ignore pollution problems, and collide with enterprises [26,27] to introduce unauthorized policies and regulations, affecting sewage charges' impacts and aims. The effectiveness of the EP promotes sustainable development. In addition, due to the low standard of sewage charge, the sewage charging system has not been fully effective in reducing pollution emissions [28], and even the standard of sewage charge collection is lower than the cost of pollution treatment, which results in the phenomenon of enterprises "paying money to discharge reasonably". This kind of non-market-based EP tool may intimidate firms to control pollution, but it seems that needs-market-oriented inventiveness drives firms to conduct green technology with internal motivation.

Another non-market-based EP tool is pollution charging. A pollution charging system is an important government environmental regulation tool, first introduced in the Environmental Protection Law (Trial). The effect of this system is to internalize the externalities of environmental pollution by incorporating external environmental factors into the internal decision-making of production and operation. However, during the implementation of the emission charging system, pollution shortly dropped off and problems came forth, such as lessening standards of charging, administrative interventions, insufficient rigidity in law enforcement, and non-standard local rates. When setting standards for sewage charges, local governments consider the affordability of enterprises and the local economic situation. Most policymakers use the national bottom line as the charging rate to avoid huge threats to enterprises' operations, coupled with ineffective implementation and lack of supervision. This results in the actual payment of pollution charges being much lower than the investment cost for process upgrading and advanced technology application.

Thus, the incentive for enterprises to participate in pollution control is limited, but rather triggers enterprises to "pay the legal sewage" and causes a reluctance to carry out sustainable development. Lacking mandatory consistency, the EP tool cannot drive enterprises to do environmental production or bettering technology. Even controlling pollution and innovating technological outputs in a short time is far away from sustainable innovation. That requires long-view-based tools as a backup.

In this context, we will discuss Chinese EP makers incorporating traditional EP with fresh styles, such as the 2018 environmental tax reform. Due to several classifications of EP instruments, the market-based and non-market-based categories will be selected to discuss the EP harmonization mechanism and its impacts on firms' STI. Market-based EP currently implemented in China includes EPT, emission trading, quotas in renewable resources, environmental information disclosures, etc. Compared to EP instruments that are only partially implemented in some areas or lack statistics to track implementation, EPT is nationally implemented for five years with 2-years of national statistical observation. Thus, we choose EPT as the classic marketed-based EP tool. As for the traditional non-market-based EP instruments, EPI has been consistently implemented since its inception and is aimed at all businesses.

2.1.2. Market-Based and Non-Market-Based EP Instruments' Relationships with Firms' STI

EP instruments are designed to prevent and reduce the harmful impacts of human activities on ecosystems. Thus, the ability to encourage firm innovation is a follow-up objective of EP's primary goals [15] (i.e., reduce pollutants, improve the environment, energy conservation, etc.). The function of EP to stimulate innovation was first observed by Porter [7]. Subsequently, researchers studied the relationship between EP instruments and innovation and found that market-based regulation is more flexible and better for facilitating technological innovation [8]. Afterward, supportive research argued that flexible EP works better on innovation, such as technology-based standards, mission trades, and tax [18,19]. Moreover, the empirical investigation found that a carbon tax instrument reduced pollution and stimulated technological innovation in Norway and Sweden [29].

However, the existing research mainly focused on the relationship between EP tools and promoting green technology, environmental performance, and economic performance [23,30–32]. Driven by EP, firms are incentivized to develop green technology to reduce their pollution.

Sustainable innovation asks firms to change their traditional method of innovating technologies, producing goods, or providing services to gain profits as well as long-term social and environmental benefits [6], as Boons et al. argued that green technology is only one of the approaches necessary to achieve firms' STI [33]. The most fundamental driver of sustainable innovation is an internal incentive to conduct technological innovation (CNCTST, 2016). In the long term, it is necessary for policymakers to harmonize non-market-based and market-based EP to lead enterprises to conduct STI rather than only focus on pollution date drop-off.

Specifically, under heterogeneous EP instruments, firms make different choices. Enterprises can reduce the pollutants and the concentration of emissions produced in the production process to a certain extent by purchasing and installing pollution control equipment and other end-of-pipe treatments. Enterprises can also adopt ways to strengthen the front-end control of pollutants, i.e., by investing in new green technologies, etc., and to increase energy utilization, improve production processes, and reduce the amount of pollutant output per unit [34].

In general, when faced with short-term, less rigid environmental regulatory policies with weak enforcement, firms prefer to adopt the less costly short-term response, i.e., purchasing pollution control equipment. In contrast, when faced with long-term, stable, and rigid EP instruments, firms prefer to adopt a less costly long-term approach, i.e., investing in green production technologies. Therefore, under the early sewage charging system, heavy polluters preferred to increase their environmental investments. The implementation of the environmental protection "fee to tax" policy will help promote the upgrading of the environmental protection investment structure of heavy polluters. Thus, the impact of EP tools on firms' STI is underexplored and deserves more attention.

Non-market-based EP, once strictly interpreted for instantly bettering environmental performance, will decrease innovation performance [20]. Neoclassical economists have pointed out that tight policy circumstances will lead to a higher expenditure of the enterprise's business cost and, in turn, will decrease firms' willingness to invest in R&D activities or new product exploitation when resources are limited. This will decrease not only innovation but also productivity and will further inhibit economic growth [35].

When non-market EP enhances firms' burden continuously, it will lead to firms' unstainable development. Because enterprises could face potential punishment at any time as well as subsequent discriminatory treatment from banks and other financial institutions, they lose the opportunity to seek sustainable development [36]. Banks and other financial institutions usually invest only in enterprises that comply with orders and control regulations. Because of the economic system, this negative impact of non-market EP will expand under a long-term view. Non-market-based EP may be efficient at accomplishing short-term environmental protection aims, but sustainability is a marathon, not a sprint—especially for firms' STI. Thus, we propose the following hypotheses:

H1a. *Market-based EP instruments, such as EPT, will increase firms' STI.*

H1b. *Non-market-based EP instruments, such as EPI, will decrease firms' STI.*

2.2. The Harmonization Mechanism of EP Instruments and Impacts on Firms' STI

2.2.1. Policy Mix Theory

"Policy mix" usually refers to a combination of two or more regulations by different departments or institutions targeting different objects [37]. The two categories are policy objective mixes and policy instrument mixes [15]. Recently, Rogge and Reichardt [38] studied a policy mix for sustainability transitions. They argued that policy mix is not mere tools' interaction but includes the policy strategy and the mix of interacting instruments.

Sorrell [39] used "policy mix" to study the combination of emission trading and other EP instruments (including carbon/energy taxes and non-market-based regulations on renewable energy). Braathen [40] explored the interactive effect of emission trading systems, environmentally related taxes, subsidies, "command-and-control" regulations, and information instruments on carbon dioxide emission and economic efficiency. Some scholars analyzed non-market-based EP combinations, such as how to use the industrial sulfur dioxide removal rate, industrial wastewater compliance rate, and industrial solid waste comprehensive utilization rate to construct a performance-based environmental regulation index system [41].

Greco et al. argued that mixed policy instruments from different fields work better than a single policy instrument on eco-innovation performance rather than on general technological innovation [15]. Frequently, however, policy mix finally becomes a "policy mess" when the mix of instruments lacks coherence [39] or when they are working toward conflicting goals [4,42].

2.2.2. The Harmonization of Non-Market-Based and Market-Based EP Instruments

In this study, we proposed that the mixed-use of market-based and non-market-based EP instruments would produce harmonious results for firms' STI. According to the "narrow" vision of the Porter hypothesis, the market-based EP approach provides firms with autonomy and helps them achieve eco-friendly development [20]. The process of environmental protection, however, is filled with uncertainty and information asymmetry. Thus, it often is in opposition to rational expectations and deviates from perfect market conditions. For example, exactly how much pollution should be controlled and how to control pollution in terms of specific indicators and approaches have a large amount of uncertainty. Environmental pollutants and their consequence are unpredictable. Exploring green technology requires a huge investment with a long return cycle and also has double externality ("knowledge spillover" and "environmental spillover"). It is highly risky for firms to gain consequent benefits [43]. Therefore, it is difficult to motivate firms to only depend on market-based policy instruments to satisfy both the goals of eco-innovation and technological innovation.

Market-based EP instruments might not be good at handling time. An effective EP portfolio might include both market and non-market-based instruments. A similar opinion was offered by Howlett and Rio [44], who concluded that an EP mix could be beneficial rather than a mess. They found that both hard and soft EP instruments could complement each other and work toward achieving a common goal of encouraging the eco-innovation of firms.

In this study, we investigated a mixed usage of EPT (market-based EP) and EPI (non-market-based EP). Usually, firms' share of governance fees for public environmental issues equals (or is less than) their marginal social costs or damage incurred. When governments only use non-market-based EP instruments, however, firms might face the risk of having to cover more than their share. Policymakers tend to force firms to take on an exact share of pollution control through every command-and-control regulation, regardless of the firms' costs [45]. So, the superposition of non-market-based instruments likely creates overfunding and overly constrains the market due to the cost exceeding the marginal abatement for pollution.

On the other hand, a market-based EP mechanism potentially incentivizes firms to decrease their marginal abetment cost and realize the equi-marginal principle [46]. It could be argued that the practice of market-based EP instruments complemented with a command-and-control policy could be cost-effective and efficient. Specifically, EPT can be used to balance the potential negative effects of EPI on the uncertainty of firms' costs on the environment. Taxation rates and tax targets are both adjustable by the government to cover the full environmental marginal damage [47]. EPT also provides a space for firms to select the most appropriate strategy for their business. If they want to develop technology and enlarge their business, which could result in more pollution, the EPT rate will provide the best estimate of how much they should be paid for this development. After considering the development price and value, firms would be able to make the most effective decision based on technological innovation to achieve sustainable development. Hence, EPT could be complementary and could be combined with EPI as an interlocking package. For these reasons, we proposed the following hypothesis:

H2. *A flexible EP portfolio, which is a combination of market and non-market-based EP instruments, will positively coinfluence firms' STI.*

2.3. The Top Manager's Reaction to EP Implementation and the Moderate Effect on Firms' STI

Firms' investment in technology innovation depends on the characteristics of their top management team (TMT). According to the upper-echelon perspective, Hambrick and Mason [48] suggested that the TMT plays a key role in offering visions, setting goals for the enterprise, and determining firms' efforts toward organizational innovation [49]. Organizational outcomes are better understood by a TMT than by a single CEO [50]. TMTs play an important role in shaping organizational characteristics by taking part in the firm's key decision-making processes [51]. The correlation is high between TMT characteristics and TMT visions and consensus toward organizational innovation, learning, or performance [52–54].

The cognitive and intellectual abilities of top executives are shaped by their work experiences, according to psychological research. Specifically, their job characteristics and experiences of success or failure shape their cognitive preferences, attitudes, and intellectual characteristics [55]. In terms of technological innovation, top executives with long-term technical experience in areas such as engineering, design, and research and development are more likely to value investment in R&D and recognize the long-term value of sustainable technological innovation for the firm. This can make them better equipped to interpret and respond to sustainable environmental policies within the organization.

Furthermore, a technical background provides the executive team with a higher level of professional experience and technical competence, which allows them to evaluate the risks of green innovation activities and be more confident in the face of green innovation uncertainty. In fact, research suggests that a technical executive team is more open to new technologies, products, and ideas and is also more tolerant of failures in sustainable technology innovation [56]. Thus, TMT, with its technical background, could balance green technology risk, R&D for technological innovation, and social responsibility to achieve sustainable progress.

In addition, based on expected utility theory, personal experience will make individuals' decision-making preferences align with their professional knowledge and thus produce behavioral biases in organizations [57]. Different experiences of corporate executives will introduce different impacts on firms' behaviors and strategies [58,59]. For example, production managers tend to pay more attention to production issues, whereas sales supervisors tend to improve the performance of firms' sales [60]. If the executives have technological experience, then their organizations likely will prefer technological investment and will emphasize R&D activities [61,62]. Executives with production, technology, or R&D experience also prefer to pay attention to and understand technological developments and prefer to invest in product and technological innovation [63]. Han et al. found that executives with technology and R&D backgrounds usually are characterized by creativity, and they play an essential role in promoting product innovation strategies and technological innovation capabilities [64]. Inventor executives with a deep understanding of the technological frontier can facilitate corporate innovation management and identify more innovation opportunities from regulations and policy [65]. Thus, technology executives may influence the company's response to EPT and EPI rather than "transferring" funds from planned R&D activities to paying for EP costs. Their decision-making process about further R&D and product plans may be less influenced by EPT than by EPI. Taken together, executives with technological backgrounds indirectly enhance firms' STI. Thus, we proposed the following hypothesis:

H3a. *TMT with technical background will magnify the positive relationship between market-based policy instruments and firms' STI.*

H3b. *TMT with technical technology background will decrease the negative relationship between non-market-based policy instruments and firms' STI.*

After literature review above and we developed a framework (see Figure 1.) to expand the research.

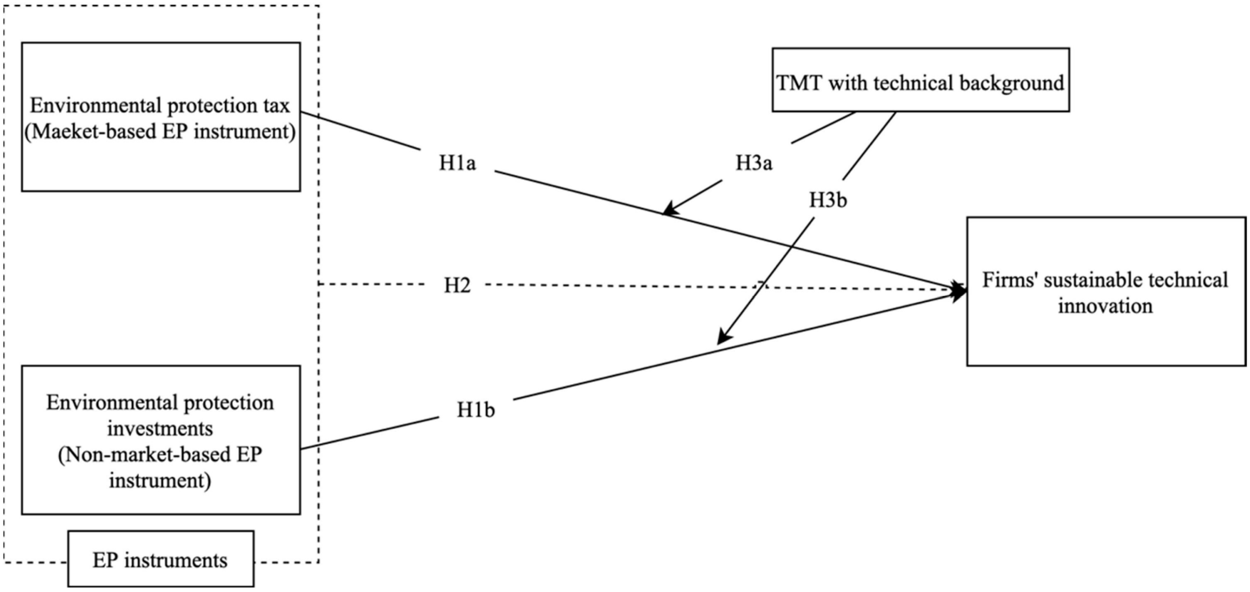

Figure 1. The research framework and hypotheses.

3. Methodology and Research Design

3.1. Samples and Data Collecting Process

In this paper, sample firms were A-Share Listed companies in China from 2015 to 2019. Since this paper uses the DID method to study the impact of the Chinese environmental protection tax that started to be implemented in 2018, the years 2015 to 2017 were selected as the control group in this paper. In addition, the duration was selected due to data on firms' R&D investment prior to 2015 being unavailable, and data on R&D investment later than 2019 has not been published. Then, we processed the original data as follows: (1) ST and *ST firms were moved because their operating data were not representative; (2) firms belonged to the financial industry according to the 2012 industry classification standard of the Securities and Futures Commission were moved, because their business was special and their accounting standards were different from firms in other industries; (3) firms with missing values of R&D investment were moved; (4) firms with the value of continuous variables belong to upper 1% and lower 1% were moved. Finally, the study collected panel data from 618 firms over the period 2015–2019, resulting in a total of 3090 observations.

The main data used in the study came from three sources: One is the Chinese Research Data Service Platform (CNRD) database. It supplies the firms' R&D investments, executive information, and patent information. Data on the financial and market of the firms came from the Resset database, which includes information on firm sales growth, firm leverage, etc. Data on firms' environmental investments came from the firms' annual reports.

3.2. Measuring Variables

3.2.1. Dependent Variable

STI was measured by the Data Envelopment Analysis (DEA) method developed by Charnes [66]. DEA has been widely used in literature for the analysis of performance with multiple outputs and multiple inputs [67]. The DEA method includes two models: the CCR model and the BCC model. The BCC model is for measuring pure technical efficiency, so it is not appropriate to be used in this study because Chinese firms have a 'scale effect' on their performance. Therefore, the CCR model of DEA, which is able to measure performance, was selected. The calculation formula of the CCR model is as follows:

$$min\vartheta_j$$

$$\sum_{i=1}^{m} \lambda_j x_{ij} \leq \vartheta_j x_0,\ i = 1, 2, \cdots, m$$

$$s.t.$$

$$\sum_{r=1}^{s} \lambda_j y_{rj} \geq y_0,\ r = 1, 2, \cdots, s$$

$$j = 1, 2, \cdots, n$$

$$\lambda_j \geq 0$$

ϑ_j is the efficiency; firms with solution $\theta_j = 1$ are regarded as relatively efficient, or benchmark firms and their performances determine the efficient frontier, whereas firms for which $\theta_j < 1$ are regarded as inefficient.

$x_{ij} = \left(x_{1j}, x_{2j}, \cdots, x_{mj}\right) > 0$ is input.

$y_{rj} = \left(y_{1j}, y_{2j}, \cdots, y_{sj}\right) > 0$ is output.

λ_j is the intensity factor that reflects the contribution of firm j in the derivation of the efficiency of another firm.

Moreover, we used the window-DEA method to reflect the time effect, in other words, to perform the horizontal comparison among decision-making units (DMUs) and the historical comparison of the same DMU. Following the previous literature, the window time in this study was a 3–4 year period [68–71].

Assuming that there are j DMUs, t time periods of data, and a time window width of d, each DMU has $t - d + 1$ time window and d efficiency value in the $f(f = 1,\ 2, \cdots, t - d + 1)$ time window. For each DMU at the $e(e = 1,\ 2, \cdots,\ d)$ time point within the $f(f = 1,\ 2, \cdots,$ $t - d + 1)$ time window, the input-oriented calculation formula is shown below.

$$min\vartheta_j$$

$$\sum_{i=1}^{d \times m} \lambda_j^{fe} x_{ij}^{fe} \leq \vartheta_j^{fe} x_0^{fe},\ i = 1, 2, \cdots, m$$

$$s.t.$$

$$\sum_{r=1}^{d \times s} \lambda_j^{fe} y_{rj}^{fe} \geq y_0^{fe},\ r = 1, 2, \cdots, s$$

$$j = 1, 2, \cdots, n$$

$$\lambda_j \geq 0$$

x_0^{fe} means the ith input of the jth DMU at the eth time point within the fth window. y_0^{fe} means the rth output of the jth DMU at the eth time point within the fth window. ϑ_j^{fe} means the optimal solution of the above model.

In the DEA model, multiple input and output factors were included in determining the efficiency of each DMU. We used R&D personnel (CNRD database) and R&D expenditure (CNRD database) as input variables. Patent grants (CNRD database), new product sales revenue, and green patents applications (CNRD database) are taken as output variables or the efficiency of each DMU. Because R&D inputs usually cannot bring outputs within one year, we, therefore, use patent grants rather than patent applications to reflect the time lag. Moreover, because the new product sales revenue on the firm level was not available, it was calculated by the average data of new product sales revenue (China Industry Statistical Yearbook 2015–2019) of the industry times firms' ROA [72] (Resset). Among the output variables, the patent grants count had zero value and was not acceptable for the DEA model; thus, we replaced the zero value with a fairly small value of 0.0001 [73].

3.2.2. Independent Variables

The market-based EP policy instrument was measured as the firm's EP tax fee. In China, the tax was implemented in January 2018.

The non-market EP policy instrument was measured by the firm's EP investment reported in the annual reports of the firms. We excluded all the punitive expenditures (such as sewage charges) and only included the government-mandated direct investments for environmental improvements. It was the sum of investment for afforestation, preventing pollution and wastewater abatement, etc. The two EP policy data were manually collected from the firms' annual reports.

3.2.3. Moderating Variable

Technical executive. The data came from the CNRD database, and it regards technical executives as managers who are experts in technology or who have worked in the department of technology and production. If none of the executives of the firm had a technical background, it was given "0". Otherwise, it was given "1".

3.2.4. Control Variables

Control variables of this study are from the Resset database: (1) firm age (measured by the difference in years between the founding year and the year 2019). It was found to negatively impact firm innovation [74,75]; (2) increased rate of main business revenue, leverage (measured by the ratio of total assets to shareholders' equity), was found to be positively related to firm innovation [76–80] and significantly influenced firm R&D investment [81–84]; (3) growth (measured by the ratio of the difference between the revenue from the main business in the current period and the revenue from the main business in the previous period to the revenue from the main business in the previous period); (4) cash (measured by the cash-to-assets ratio) was found to be positively correlated to R&D investments [85]; (5) cost management (measured by the management fee rate) was found negatively affect technical efficiency [86,87].

The means, standard deviations, and correlations of the main variables are presented in Table 1.

3.3. Data Analysis Strategy

Firstly, we employed a difference-in-differences (DID) estimator to study the effect of EP on firm STI and a panel OLS estimator to study the policy mix effect, the moderating effect of technical executives on the relationships between EPI and STI as well as EPT and STI. DID is frequently used to study observational data regarding the effects of exogenous events when subjects cannot be randomly assigned to a treatment group and a control group [88]. The following is a linear ordinary least squares (OLS) specification with two-way fixed effects:

$$TIP_{i,t} = \beta_0 + \beta_1 post_t \times treatment_i + \beta_2 control_{i,t} + \beta_3 industry_i + \gamma_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

The subscript I denotes a firm, and t is the year. $post_t \times treatment_i$ is the interaction between a dummy code unit for firms ($treatment_i$) that should pay the EPT and a dummy variable coded unit for the post–2018 ($post_t$). $treatment_i$ was given "0", which means firms not paying the EPT, and was given "1", which means taxable firms. $post_t$ was given "0" means years before 2018, and "1" means the year 2018 and subsequent years. The coefficient β_1 represents a difference between firms both paying or not paying the EPT in the post-2018 period compared to the pre-2018 period. The $treatment_i$ and post_t dummy is omitted, as it would be collinear with the firm and year fixed effects [89]. γ_i is the firm fixed effects, and μ_t and ε_{it} are error terms.

Table 1. Summary statistics and correlation coefficients for the key variables.

	Count	Mean	Sd	Max	STI	EPT	EPI	Technical Executive	Age	Growth	Manage Cost	Leverage	Cash
STI	3090	0.5807	0.1218	1	1								
EPT	515	0.4185	1.3953	12.633	0.0445	1							
EPI	3090	0.0147	0.0217	0.1146	−0.114 ***	0.200 ***	1						
Technical Executive	1482	0.5007	0.5002	1	−0.0190	0.0984	0.0495	1					
Age	3090	2.9310	0.2747	3.6636	−0.111 ***	0.102 *	0.140 ***	0.0336	1				
Growth	3090	0.1427	0.3464	2.1684	0.0646 ***	−0.0482	−0.0407 *	0.0104	−0.0841 ***	1			
Manage cost	3090	0.0951	0.1691	7.2843	0.0408 *	−0.165 ***	−0.0896 ***	−0.0236	−0.0883 ***	0.152 ***	1		
Leverage	3090	2.1943	5.2525	206.89	0.0363 *	0.0123	0.0439*	0.0542 *	0.0324	−0.0355 *	0.0275	1	
Cash	3090	0.1311	0.0953	0.4797	0.0411 *	−0.0860	−0.0656 ***	0.0429	−0.0224	0.00425	0.0185	−0.0567 **	1

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Then, panel OLS regressions were employed to study the rest of the hypotheses. We extracted firms paying EPT from the dataset to analyze the micro-effects of EP instruments. Moreover, we included the fixed-effect estimator in the regressions to control for unobservable firm factors that might influence STI. To be noted, during our observation period, Sino-US trade friction happened. These macro-shocks may have impacts on industries. It was found that multidimensional shocks in the real economy often lead to different reactions in the industry. The effect of the industry's reaction can be consistently and properly obtained in a panel data context [90]. Thus, to prevent these unobservable common shocks and their different impacts on industries, we also controlled the industry-time interactive fixed effect. This strategy has been widely used in recent literature [91–95]. In addition, we controlled clustered robust standard errors at the province level to avoid serial correlations and heteroskedasticity.

The main data analysis tools of this study are R and Stata17.

4. Data Analysis

4.1. Hypotheses Test

To test H1a, which states that EPT will increase STI, DID models were used. The results are presented in Table 2. They show that EPT firms have 1.4% higher STI than non-EPT firms ($p < 0.05$, see model 1). Then, industry dummies and a set of firm-level controls were added, and it turns out that EPT firms have 1.1% higher STI than non-EPT firms ($p < 0.1$, see model 2). Thus, all three models show that EPT has a statistically significant positive impact on STI. Thus, H1a is supported.

Table 2. DID estimates on STI.

	Model 1	**Model 2**
post *taxtreat	0.01425 **	0.01151 *
	0.00686	0.00671
Age		−0.28433 ***
		0.06724
Growth		0.00001
		0.00087
Management cost		−0.02201 ***
		0.00595
Leverage		0.00084 **
		0.00038
Cash		0.05451
		0.03696
Constant	0.57853 ***	0.1405 ***
	0.00104	0.19667
Fixed effects	Firm, Year	Firm, Year
Industry dummies	No	Yes
Observations	3090	3090
R-squared	0.43758	0.44250

Notes: 1. Province clustered standard errors were presented under coefficients; 2. *** $p < 0.001$, ** $p < 0.05$, * $p < 0.10$.

To test H1b and H2, we estimated fixed-effect OLS regressions. As shown in model 2 of Table 3, EPI has a negative impact on STI (β = −0.54, $p < 0.1$). Thus, H1b is supported. The interactive term of EPT and EPI positively affects STI (β = 3.7129, $p < 0.1$, see model 6). Thus, H2 is supported.

Finally, to test H3a and H3b, we added a moderating variable: Technical executive. The interaction terms Technical executive ∗ EPT and Technical executive ∗ EPI both statistically significantly predict STI ($\beta = 0.04,\ p < 0.1;\ \beta = 1.1,\ p < 0.05$; respectively). This indicates that a firm that has a technical executive is more likely to have better STI. Therefore, H3a and H3b are supported.

Table 3. Fixed effects OLS regressions on STI.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
EPT	0.04598 *		0.05068 *	0.02830	−0.01863	
	0.02669		0.02531	0.02489	0.06002	
EPI		−0.54097 *	−1.14048 **	−1.07970 *		−0.80446
		0.27015	0.51908	0.53613		0.51000
EPT *EPI				3.71294 *		
				2.18392		
Technical executive					−0.03616	−0.02817 **
					0.02869	0.01358
Technical executive *EPT					0.04043 *	
					0.02192	
Technical executive *EPI						1.10375 **
						0.50639
Age	−0.27273	−0.39825 **	−0.36667	−0.30670	2.0778	−0.40521
	0.94956	0.18870	0.96546	0.94846	2.29738	0.34806
Growth	0.00858	−0.00315	0.00096	0.00418	0.01196	0.01067
	0.02272	0.00921	0.02504	0.02542	0.05570	0.01646
Manage cost	0.31397	−0.02308 ***	0.35422	0.35275	0.19871	−0.32959 *
	0.24428	0.00598	0.26318	0.26317	0.85678	0.17359
Leverage	0.00065 **	0.00149 ***	0.00082 ***	0.00080 ***	0.02458	0.00168
	0.00028	0.00031	0.00028	0.00028	0.08479	0.00133
Cash	0.05303	0.08639	0.08965	0.07935	−0.25673	0.03552
	0.10183	0.05504	0.11073	0.11180	0.22368	0.0718224
_Cons	1.29884	1.752701 ***	1.602386	1.428695	−5.802588	1.823488 *
	2.870439	0.5569115	2.918955	2.866922	7.044497	1.023708
Fixed effects	Firm, Year *Industry	Firm, Year *Industry	Firm, Year *Industry	Firm, Year *Industry	Firm, Year *Industry	Firm, Year *Industry
Observations	515	1395	515	515	252	670
R-squared	0.7094817	0.5323189	0.7182822	0.7210598	0.9148703	0.7821413

Notes: 1. Province clustered standard errors were presented under coefficients; 2. *** $p < 0.001$, ** $p < 0.05$, * $p < 0.10$.

4.2. Robustness Check

Firstly, the DID approach of policy effect believes that even when there are no policy changes, trends in STI of treated and untreated firms would change over time in parallel. To test the parallel trend, this study uses an event study method and sets up the following regression model based on the calculation formula of (1) $TIP_{i,t} = \beta_0 + \beta_1 post_t \times treatment_i + \beta_2 control_{i,t} + \beta_3 industry_i + \gamma_i + \mu_t + \varepsilon_{i,t}$

$$TIP_{i,t} = \alpha + \sum_{j=-3}^{2} \beta_j TAX_{i,j} + \gamma_i + \mu_t + \varepsilon_{i,t} \tag{2}$$

$TAX_{i,j}$ is a dummy variable that takes the value of "1" when firm i paid EPT in the year j and "0" otherwise. Thus, β_0 is the effect in the period of implementing EPT, β_{-3} through β_{-1} are the effects in periods 1–3 before the implementation, and β_1 through β_2 are the effects in periods 1–2 after the implementation. Period one before the implementation was used as the base group of the model [96] and, thus, was not included in the regression. If β_{-3} through β_{-2} are significantly zero, then the common trend assumption is established, and β_1 through β_2 are the effects after the implementation. The coefficients of β_{-3} and β_{-2} are not significantly different from 0, and β_0 is significantly different (see model 1 of Table 4). Thus, the parallel trend passed the examination. In addition, we also employed a placebo test by changing the dependent variable to firm age, which is not affected by EPT (see model 2 of Table 4), and sample firms from retailing industry are not affected by EPT policy as the treatment group (see model 3 of Table 4). Both $post * taxtreat$ and $post * faketreat$ are statistically insignificant, which verified the robustness of the conclusions of H1a.

Table 4. DID common trend assumption and placebo tests.

	Model 1 (STI)	**Model 2 (Age)**	**Model 3 (STI)**
before3tax	0.0054983		
	0.0074274		
before2tax	0.0160232		
	0.0095138		
currenttax	0.0541049 ***		
	0.0084794		
after1tax	−0.0123378		
	0.0101929		
post × taxtreat		−0.0048147	
		0.002947	
post × aketreat			0.0015744
			0.0111456
Age	−0.0038325		−0.2907942 ***
	0.0081176		0.0675471
Growth	−0.0002707	0.0001709	0.0000222
	0.0005769	0.0004822	0.0008651
Manage cost	0.002272	0.0033239	−0.0219516 ***
	0.0068008	0.0038152	0.0059157
Leverage	0.0008056 ***	0.0000435	0.0008696 **
	0.0002618	0.0000629	0.0003918
Cash	−0.0011249	−0.0130806	0.0573884
	0.0178809	0.0105779	0.0366584
_cons	0.6183107 ***	2.93304 ***	1.425498 ***
	0.0202456	0.0013076	0.1976628
Industry dummies	Yes	Yes	Yes
Firm fixed	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes
Observations	3090	3090	3090
R-squared	0.2479216	0.9935008	0.4420072

Notes: 1. Province clustered standard errors are presented under coefficients; 2. *** $p < 0.001$, ** $p < 0.05$; 3. post × faketreat denotes the interactive term of firms belonging to retailing industry and the year of post-2018; 4. "before3tax", "before2tax", "currenttax after1tax" denote β_{-3}, β_{-2}, β_0, β_1, respectively.

Secondly, to prevent the sample selection bias from coming from missing data of the dummy variable technical executive (presence of technical executives), the two-stage Heckman method is applied to identify and correct the selection bias. In the first stage, a dummy variable of whether the technical executive has missing values was used as the dependent variable in a probit regression. Covariates include total assets and the number of years of company establishment was controlled. In the second stage, the inverse Mills ratio (IMR, obtained from the first stage) was then examined as a control variable. It turns out that IMR is not significant. Thus, sample selection bias is less concerning. Table 5 shows that the significance of the interactive terms remained insignificant, which means the missing value of technical executive did not cause serious sample selection bias.

Thirdly, we used an alternative estimation model to check the robustness of the result. The efficiency value calculated by DEA is between 1 and 0, and, thus, many studies use the tobit model to deal with the data within a certain range [97]. Therefore, we estimated with random-effects tobit regression with bootstrapping methods (N = 1000) to check the robustness. It turns out that β is 2.1058 ($p < 0.05$). We also employed the method proposed by Bai [90] to estimate the panel data models with interactive fixed effects by using Sino-US trade friction as the common factor. The result indicated that β is 3.7282 ($p < 0.10$).

Table 5. Two-stage Heckman examinations.

	Model 1	**Model 2**
EPT	−0.0306389	
	0.0609536	
EPI		−0.8026819
		0.51504
Technical executive	−0.03914	−0.02807 *
	0.0269629	0.0137896
Technical executive × EPT	0.0436851 **	
	0.0203887	
Technical executive × EPI		1.100706 **
		0.5144984
IMR	1.980804	−0.0344477
	2.640215	0.2528263
Age	3.076095	−0.4023683
	3.060587	0.3500913
Growth	0.0222027	0.0108425
	0.0585588	0.016819
Manage cost	−0.0378281	−0.3309729 *
	0.9370732	0.1770222
Leverage	0.0412988	0.0016691
	0.0833313	0.0013516
Cash	−0.2717694	0.0364164
	0.2194006	0.0723632
_cons	−10.38223	1.842441 *
	10.99439	1.042354
Fixed effects	Firm, Year × Industry	Firm, Year × Industry
Observations	252	670
R-squared	0.9159613	0.7821674

Notes: 1. Province clustered standard errors under coefficients; 2. ** $p < 0.05$, * $p < 0.10$.

Taken together, the three robustness checks all support H2.

5. Conclusions

This study explores Chinese EP instrument harmonization and its impact on firms' sustainable technological innovation. We observed 618 Chinese listed firms with constant technological productivity lasting five years. According to DID model results, China's environmental tax reform in 2018 significantly incentivized firms' STI. Fixed panel OLS results showed that the harmonization of EPT and EPI is complementary and significantly promotes firms' STI jointly. In further research on the effect mechanism, we testified top management team with technical background could increase the flexibility of environmental policy implementation, thereby amplifying positive impacts and dampening negative ones. The findings of this study have theoretical contributions and are suggestive of firm innovation management strategy and government policymakers.

5.1. Main Findings and Their Theoretical Contributions

Following the seminal work done by Porter and his colleagues, the impacts of EP instruments on firms' innovation have gained much research attention in recent decades at the country level [4,98,99], industry level, and firm level [100,101]. In exploring the influence of EP instruments on firms' technological innovation, the main research conclusions agree with the 'narrow' hypothesis arguing that proper and flexible EP instruments implementation could advance innovation [8]. According to their study, market-based EP should be more flexible, tending to focus on the protection outcomes to set tax rates or technology standards, compared with strict non-market-based EP requiring direct expenditures in the protection process.

Recently the discussion of mixed EP instruments has been gaining research attention, and scholars believe that the characteristic of proper and flexible EP combination includes the coherent goals of policy instruments [102,103]. However, there is no empirical evidence of the co-effect of the market and non-market-based EP instruments on firms' STI. This study is the first time this research question has been explored. The findings of this study have the following academic contributions:

First, market-based EP instrument EPT facilitates firms' STI. The main reason is that market-based EP internalizes the environmental costs borne by society and adjusts the production and product costs of firms using price instruments [104]. It is a cost-efficiency tool to reduce pollution and avoid decreasing the incentive for R&D. For example, China EPT brings that external cost into the transaction, ensuring that the buyer pays the full marginal social cost of the good. Firms pay for their pollutants or emissions through the taxation system, not instantly paying money. This part of the business cost may not be added to the price of their products. Thus, the incentive provided by the tax ensures enterprises afford their public share of environmental protection. The consistency and certainty of taxation offer some choice space for firms' further management strategies to face different market circumstances; specifically, they could adjust this part of the cost by enlarging or restraining production in a thriving or sluggish economy to accomplish firms' sustainability.

Second, the non-market-based policy instrument EPI is negatively related to STI. This finding keeps in line with the research by Stavins [17], who found that non-market-based policy would freeze enterprises' capital which was R&D usage at the outset from a long-term view. Single use of EPI for several years may cause stringent EP circumstances, which will depress R&D activities and lead to unsustainable innovation. Strict EP circumstances put firms in the dock to make innovation strategies under a changeable market. It usually focuses on the process of environmental protection, such as EPI requiring firms to invest a certain amount of money for afforestation or river restoration. Facing downward economic pressure, firms will meet serious difficulties in accomplishing sustainable innovation because the EPI fees squeeze out other expenditures, including money for R&D activities.

Third, the two types of EP instruments create a positive impact on firms' STI. This conclusion fills the gap of mixed EP impact on technological innovation performance in a sustainable view. Scholars are starting to think much of mixed policy towards technology innovation [105]; for example, Greco et al. put an environmental policy together with an innovation policy to explore the interaction effect on technological innovation [15]. Others broadly study the influence of mixed policy on innovation [38,106,107]. Based on that, our study put forward the interaction between market and non-market-based EP instruments and found this portfolio is beneficial for advanced firms' STI.

Furthermore, recent literature suggests that firms' TMT will influence firms' technological innovation [108]. The findings are similar to the previous conclusion that TMT with a technical background promotes firms' R&D expenditures and technological innovation [109]. This study pushes it forward and demonstrates that technical executives moderated the impact of EPT and EPI on firms' STI. Thus, it is the first time demonstrating that the effect of EP instruments also depends on firms' TMT technical backgrounds, which addresses the attention of enhancing a long-term sustainable view of innovation management.

In sum, according to Boons et al., sustainable innovation includes the comprehensive picture of technological innovation rather than the firms' patent count of green technology [33]. However, a pile of papers has tested how Chinese policy instruments influence green inventions [23,30–32]. They used firms' patents of green technologies to represent the sustainable innovation of the firm. This is not quite accurate. The STI performance shall include not only green technology but also constant technological innovation, commercialization, and social benefits. This study contributes to the Porter hypothesis by demonstrating that non-market-based policy instruments of EP policy tools can complement market-based EP policy tools in facilitating firms' STI, and both kinds of EP policy instruments' impacts will be positively moderated by TMT with a technical background.

5.2. Policy Implications

According to the findings of this study, we suggest the following suggestions to policymakers:

Firstly, to help firms improve sustainable technological innovation, governments could mainly depend on market-based EP instruments and achieve both economic and environmentally sustainable development.

Secondly, the government should remain cautious in applying non-market-based EP instruments [110]. The EPI in this study may increase firms' costs and restrain their motivation to follow R&D expansion. The instrument may disrupt the effective price mechanisms of the market that allows producers and consumers to respond to real market situations. Although it raises firms' attention to protect the environment, it fails to be an incentive for firms' R&D expenditure and their generation of new processes and technology.

Thirdly, mixed application of market and non-market-based EP instruments should enlarge the positive effect of market-based policy instruments on firms' STI. This gives government flexibility as well as effectiveness in regulating firms' environmental protection behaviors. A piece of similar evidence was found in the northwest region of England [111]. This study responds to the appeal of "strategic policy intelligence", which requires a dynamic view of EP instruments interaction and gives additional evidence to the "weak" version of Porter's hypotheses [37]. We agree with Tidd that the innovation issue is not the only issue of making EP, and governments should use market and non-market-based mixed EP portfolios to stimulate firms' STI [112].

Moreover, in order to positively react towards EP instruments, a firm would better involve executives with technical backgrounds. They will help firms to understand technological developments, invest in R&D [63], apply product innovation strategies [64], and identify more innovation opportunities [65]. The most important role of enhancing TMT's creativity through technical executives is aiming to better interpret EP instruments, rather than conducting innovation management.

5.3. Limitation and Further Research

The limitations of this study are as follows:

First, the sample firms all came from China. To generalize the findings of this study to other countries, more evidence from other countries should be investigated.

Second, this study only used EPT to stand for market-based policy instruments and EPI to represent non-market-based policy instruments exploring the respective impacts and co-effect on firms' STI. EP instruments are quite enriched; for example, beyond the EPT and EPI, emissions trading, technology standards setting, pollution penalties, and government subsidy policy also play major roles in addressing the issue of sustainable innovation [19]. The reason our study applies EPT is that it is China's most recent policy reformation since January 2018 from a direct pollution fee which is a non-market-based EP to a marked-based EP instrument. Moreover, the emission trading system just operated in July 2021; thus, its effectiveness is still waiting to be examined. As for EPI, it has been implemented for a long time, and the data of selected samples is coordinated. In the future, more instruments of EP need to be studied to obtain a more robust conclusion on the positive effect of market-based policy instruments and mixed usage of both types of policy instruments on firms' STI.

Third, in this study, we measured TMT with technical background by collecting data on whether there is an executive with a technological background in the teams. In the future, the number of technology executives and the decision-making scope data would also need to be collected by a survey to more comprehensively reflect their technological expertise and preference for technological innovation expenditure. Since CEOs and general executives hold differing levels of decision-making power and influence within their teams, group regressions may be employed to examine potential heterogeneity in the interpretation of environmental policies between CEOs and general executives with technical backgrounds. Such analyses would shed light on how technical expertise among executives of different levels may impact their understanding and response to environmental policy.

Last but not least, further analysis needs to start from the perspective of industry heterogeneity to observe and explore the mechanisms by which different environmental policies affect innovation performance in different industries. Especially for manufacturing enterprises in different technology fields, it is worthwhile to analyze in depth what combination of environmental policies can promote sustainable technological innovation more effectively while maximizing environmental benefits. We hope to make practical and meaningful policy recommendations for the development of sustainable manufacturing in China.

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