

Environmental Technical Standards and the Green Transition of China's Manufacturing Industry

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Abstract: Distinct from the existing literature conforming to the Porter hypothesis which emphasizes the technological innovation mechanism, this paper examines the mechanism of technological transformation through which environmental technical standards influence the manufacturing industry in reducing emissions and improving efficiency (i.e. green transition). Furthermore, drawing upon enterprise samples from the databases of Chinese Industrial Enterprises and Chinese Industrial Pollution Sources from Major Monitored Enterprises, it empirically validates the results of the theoretical analysis. Overall, our research reveals that environmental technical standards can propel manufacturing enterprises to reduce pollution and increase productivity by following an incremental path of technological transformation, thereby achieving a green transition. Moreover, environmental technical standards indirectly promote green technology innovation in the upstream equipment manufacturing enterprises. Heterogeneity analysis further shows that environmental technical standards have a stronger effect of green transition on those companies with higher pollution emission intensity, lower productivity, slower capital renewal and stronger financing capacity prior to implementing the environmental policies.

Keywords: Environmental technical standards green transition, technological transformation, Porter hypothesis

JEL Classification Code: L25, L51, Q55

DOI: 10.19602/j.chinaeconomist.2022.09.02

1. Introduction

Since the beginning of the reform and opening-up period, China's manufacturing industry has made tremendous strides. The country's global share of manufacturing value added experienced a sharp increase, from less than 3% in 1990 to around 28% in 2018. Among the world's 500 or so major industrial products, China ranks first for about 220 of them in terms of manufacturing output. However, the country's overall manufacturing productivity is still significantly lower than that of developed countries, and even lagging behind some emerging economies (Ding & Du, 2018). The extensive development model of the traditional manufacturing industry, characterized by high pollution and high energy consumption levels, has given rise to a range of environmental and resource problems. According to some calculations (Fu *et al.*, 2021), in the 18 years from 2000 to 2017, the energy consumption of 28 sub-sectors of the manufacturing industry more than doubled, from consuming 600 million tons of standard coal equivalent in 2000 to nearly 2 billion tons in 2017. Concomitantly, carbon

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dioxide emissions increased by 2.36 times. The 14th Five-Year Plan for National Economic and Social Development and the Long-Range Objectives for 2035, adopted in October 2020, put forward the goals of “maintaining the basic stability of the proportion of the economy taken up by the manufacturing industry” and “accelerating the green and low-carbon development.” What is at stake is how to reconcile the two seemingly paradoxical development goals? In particular, in light of the requirement of “implementing the strictest ecological and environmental protection system” as outlined in the report to the 19th National Congress of the Communist Party of China (CPC), it is of increasing relevance to raise two questions: How to realize a green transition¹ of the manufacturing industry accommodating both emission reduction and efficiency improvement? And what is the effective path for the transition?

Among the existing research, many scholars have - from the perspective of the “Porter hypothesis” - examined whether environmental regulations could induce coordinated development between environmental protection and economic growth through technological innovation (Dechezleprêtre *et al.*, 2019). For example, Lanoie and colleagues (2011) empirically examined the relationship between environmental regulations, technological innovation, and economic performance drawing on the survey data of 4,000 companies in seven industrialized countries. Their study showed that while strict environmental regulations positively propelled companies to innovate in environmental technologies, they generally hindered the economic performance of firms as the compensation for innovation failed to offset the corresponding compliance costs. However, others had contrary findings. Based on the panel data of 13 manufacturing sub-sectors in eight European countries from 2001 to 2007, the empirical analysis of Franco and Marin (2017) found that environmental tax significantly promoted technological innovation measured by the number of patents at the industry level, which further improved industrial productivity. Their study hence concluded that green taxes in general have a positive impact on productivity. In a similar vein, taking China’s pilot emission trading policy as an example, Ren and colleagues (2019) found that these policies enabled the pilot areas to secure a “win-win” of environmental protection and economic performance primarily through technological innovation. Deng and others (2021) also concluded that the compensation reward of innovation was greater than the compliance costs resulting from China’s “energy-saving and low-carbon” policies.

Besides technological innovation, technological transformation through updating production equipment and absorbing advanced production technology has always been an important path for advancing technological progress and productivity in China’s manufacturing industry (Shi & Li, 2019), and therefore it should also be a viable option for the green transition of enterprises driven by environmental regulations (Perino & Requate, 2012), especially for firms with insufficient R&D capacities (Shao *et al.*, 2020). The study of Zhang and Lu (2018) showed that regulations on green production impelled enterprises to meet cleaner production standards by deploying new pollution control and production equipment, rather than through technological innovation. Similarly, taking the emission reduction plan under the 11th Five-Year Plan as a case study, Fan *et al.* (2019) found that polluting enterprises managed to meet stricter environmental regulations chiefly by increasing investment in equipment for recycling and emission reduction. However, compared with the strand of literature conforming to the Porter hypothesis, research concerning the effect of environmental regulations on a green transition from the perspective of technological transformation is noticeably scant. Although the studies of Zhang and Lyu (2018) and Fan *et al.* (2019) did illustrate how companies adapted to technological transformation, they failed to further analyze and verify the effect of technological

¹ According to the definition of the research group of the Institute of Industrial Economics of the Chinese Academy of Social Sciences (2011), “green transition” is a process by which an industry moves towards the goals of using energy and resources more effectively, reducing pollutant emissions and other environmental impacts, improving labor productivity, and enhancing sustainable development capabilities. The focus is on bringing out a coordinated development between environmental protection and economic benefits. Drawing on this concept, this paper defines the green transition of the manufacturing industry as a process by which manufacturing enterprises change their original production and operation methods to achieve both emission reduction and efficiency enhancement.

transformation on companies' environmental and economic performance. Moreover, these analyses, by and large, regarded technological transformation as a mere alternative to technological innovation while falling short of accounting for their complementary relationship. In fact, when looking at the formation conditions of technological innovation, technological transformation provides the essential market demands for technological innovation, and the latter provides technical support for the former (Guo & Peng, 2021).

Notably, although domestic literature assessing environmental policy effects abounds, the focus has been on environmental regulations based on the traditional total-capacity controlling method or market incentives. These studies have primarily examined the "two control areas" (SO₂ control area and acid rain control area) (Shi *et al.*, 2017), the reduction emission plan under the 11th Five-Year Plan (National Plan for Controlling the Total Emissions of Major Pollutants during the 11th Five-Year Plan Period) (Fang *et al.*, 2020) and "ten atmospheric regulations" (Air Pollution Prevention and Control Action Plan) (Luo & Li, 2018), as well as the pricing mechanisms for pollutant discharge (Guo *et al.*, 2019), and pilot emission trading schemes (Tu & Chen, 2015). They have largely left out those environmental regulations based on technical standards, which have been widely referenced in industrial production and transportation. Moreover, only a small portion of the existing empirical studies used pollution data at the enterprise level (Chen *et al.*, 2020; Chen, 2020), but the majority used regional or industry-level pollution data (Lin & Tan, 2019; Shao *et al.*, 2019; Cai *et al.*, 2020), which may fall short of capturing the mechanism of influence of environmental regulations at the micro level.

In view of the above, from the perspective of technological transformation and drawing upon data reflecting enterprises' pollution emissions at the micro level, this paper aims to theoretically and empirically examine the policy effect of environmental regulations in the form of technical standards on the green transition of Chinese manufacturing enterprises, as well as investigate the mechanism of influence. To be more specific, we first bring environmental technical standards in the model framework of Xepapadeas and de Zeeuw (1999), and theoretically investigate the mechanism through which this type of environmental regulation affects manufacturing enterprises in terms of emission reduction and productivity improvement. We then empirically test the theoretical analysis by constructing a difference-in-differences (DID) model based on the policy effect of China's first implementation plan of cleaner production standards in 2003. Empirical data draw upon two databases during the period of 1998 - 2006, namely the Chinese Industrial Enterprises database and the Chinese Industrial Pollution Sources from Major Monitored Enterprises databases. Finally, we draw the conclusion that under the rigid pressure of environmental technical standards, manufacturing enterprises opt for a more incremental path of technological transformation to achieve a "win-win" of pollution reduction and productivity improvement. This policy effect is more pronounced for enterprises with a greater demand for technological transformation and stronger financing capacities. Moreover, the technological transformation needs of the regulated enterprises can prompt green technology innovation in the upstream equipment manufacturing enterprises.

Our research contributes to the literature in three aspects: (1) Distinct from the technological innovation mechanism mainstreamed by the Porter hypothesis, this paper reveals an incremental path of technological transformation manufacturing enterprises take to comply with environmental regulations; that is, while strengthening end-of-pipe treatment, enterprises accelerate the investment in replacing traditional, backward equipment with more advanced and environmentally friendly ones in their production - a process we define as "capital renewal." And through capital renewal, enterprises can improve the utilization efficiency of energy and resources and optimize the energy consumption structure, thereby achieving a green transition. This perspective has important policy implications for promoting a high-quality development in China's manufacturing industry. (2) In the context of environmental regulations, this paper expands the analytical scope of the Porter hypothesis by investigating the impact of technological transformation of downstream industries on stimulating green

technology innovation in upstream industries. (3) Combining microscopic theoretical models with the rarely used databases of Chinese Industrial Pollution Sources from Major Monitored Enterprises, this paper complements the existing research on environmental policy assessments by examining the policy effect and mechanism of influence of environmental technical standards at a micro-level.

The remainder of this paper is structured as follows: The second section is about theoretical analysis, the third section is on empirical design, the fourth section reports the benchmark regression results, the fifth section is about mechanism testing, the sixth section is on heterogeneity analysis, and the concluding section summarizes the results and proposes some policy suggestions.

2. Theoretical Analysis

2.1 Model Construction

Building on the model proposed by Xepapadeas and de Zeeuw (1999), this research introduces a manufacturing enterprise that uses machines of different ages for production. The age of the machine is $\alpha \in [0, h]$, where h is the longest lifespan of the machine. $v(\alpha)$ and $s(\alpha)$ represent respectively the output and pollution emission of the machine at the age of α . As machines wear off, their performance and efficiency decrease, and newer machines are often designed with more advanced production and environmental protection technologies. Therefore, it can be assumed that the older the machine is, the lower the production output and the larger the emission output, that is, $v'(\alpha) \leq 0$, $s'(\alpha) \geq 0$. $x(t, \alpha)$ is the company's stock of machines at the age of α in year t , and the total output of the company in year t is:

$$Q(t) = \int_0^h v(\alpha) x(t, \alpha) d\alpha \quad (1)$$

Assuming that there is a trading market for machines of different ages ($\alpha \in [0, h]$), $b(\alpha)$ is the market price of machines at the age of α . In general, older machines consume more energy and fossil fuels during operation, and their working efficiency decreases with time. In addition, the serving age α of an old machine is closer to its time of obsolescence h . In other words, the service life of an old machine is shorter, rendering its market price lower. On this premise, we set the price of a machine as a decreasing function of its age, i.e. $b'(\alpha) \leq 0$. At the same time, for the simplicity of the analysis, we assume that the capital factor market is perfectly competitive, meaning that the price of a machine is not influenced by the demand of a single manufacturing firm, but is purely dependent on the age variable. $u(t, \alpha)$ is the number of machines of age α purchased ($u(t, \alpha) > 0$) or sold ($u(t, \alpha) < 0$) in year t , and the total cost (or total revenue) of the company from trading machines in year t is:

$$T(t, \alpha) = b(\alpha)u(t, \alpha) + \frac{1}{2}u^2(t, \alpha) \quad (2)$$

Where, the first item on the right side of the equation is the direct purchase cost of machines, and the second item reflects the adjustment cost of buying and selling the machines, including transaction, installation, debugging, etc.

On this premise, now consider that the government imposes a mandatory environmental technical standard, forcing the manufacturing company to install filtering equipment with a pollution treatment capacity not lower than δ ($\delta \in (0, 1]$) on each machine in operation. The larger δ is, the higher the requirement for pollution treatment, and the stricter the imposed environmental technical standard. The market price of each filter equipment is $\frac{\gamma}{2}\delta^2$, which is positively related to its pollution treatment capacity. This means that the marginal abatement cost of the manufacturing firm increases (Ulph, 1996).

The total pollutant discharge of the manufacturing enterprise is:

$$S(t) = \int_0^h s(\alpha)(1-\delta)x(\alpha, t) d\alpha \quad (3)$$

This number depends not only on the production scale of the company, that is, the number of machines in operation, but also on the pollutant discharge of each machine, which is negatively correlated to the pollution treatment capacity of the filtration equipment.

When the output price p is known, the manufacturing firm chooses to buy or sell machines of different ages at different points of time to maximize its profits. At this point, the objective function is presented as²:

$$\max_{\{u(t,\alpha)\}} \pi \int_0^\infty \int_0^h \{ [pv(\alpha) - \frac{\gamma}{2} \delta^2] x(t, \alpha) - [b(\alpha)u(t, \alpha) + \frac{1}{2}u^2(t, \alpha)] \} d\alpha dt \quad (4)$$

$$s.t. \frac{\partial x(t, \alpha)}{\partial t} = \frac{-\partial x(t, \alpha)}{\partial \alpha} + u(t, \alpha), \text{ or } \frac{\partial x(t, \alpha)}{\partial t} + \frac{\partial x(t, \alpha)}{\partial \alpha} = u(t, \alpha) \quad (5)$$

$$x(0,0) = 0, \quad x(t, \alpha) \geq 0 \quad (6)$$

The above is a linear partial differential equation which sketches out how to arrive at an infinite horizon optimal control with transition dynamics (Carlson *et al.*, 1991), where, $x(t, \alpha)$ is the state variable. Constraint (5) shows that the changing rate $\frac{\partial x(t, \alpha)}{\partial t}$ of the stock of machines of a given age α is equal to the reduced stock $\frac{-\partial x(t, \alpha)}{\partial \alpha}$ of machines of that age with time and the number of newly purchased machines of that age $u(t, \alpha)$. Constraint (6) means that the number of machines of any age at any point in time is non-negative, and the manufacturing firm does not possess the most advanced machines at the beginning of the period.

By solving the Hamilton equation,³ the objective function of the aforementioned how to arrive at an optimal control at the steady state level can be revised as follows:

$$\max_{\{u(\alpha)\}} \pi \int_0^h \{ [pv(\alpha) - \frac{\gamma}{2} \delta^2] x(\alpha) - [b(\alpha)u(\alpha) + \frac{1}{2}u^2(\alpha)] \} d\alpha \quad (7)$$

$$s.t. \dot{x} = u(\alpha), \quad x(0) = 0, \quad x(\alpha) \geq 0 \quad (8)$$

At the steady state level, the average machine age g , pollution emission intensity θ and average machine productivity level f are respectively recorded as:

$$g = \frac{\int_0^h \alpha x(\alpha) d\alpha}{\int_0^h x(\alpha) d\alpha}, \quad \theta = \frac{s}{q}, \quad f = \frac{\int_0^h v(\alpha) x(\alpha) d\alpha}{\int_0^h x(\alpha) d\alpha} \quad (9)$$

Equation (9) includes the core indicators of this paper. The average age of machines g reflects the age structure of the company's fixed capital used for production and operation. The smaller the variable g is, the newer the fixed capital - meaning that the company uses relatively modern production equipment. Therefore, g can be used to measure the degree of the company's capital renewal. Pollution emission intensity θ is the pollution emission per unit output. The lower the variable θ is, the greener the company's industrial production activities. Since the model only considers the capital factor, f reflects the average productivity level of the company.

2.2 Model Analysis

For the simplicity of analysis and calculation, following the strategy of Xepapadeas and de Zeeuw (1999), this paper sees the above equations as linear, and further normalizes a machine's maximum lifespan h and the price factor of the filtering equipment γ to 1. As such, this paper assumes the below:

$$v(\alpha) = \alpha(1-\alpha), \quad s(\alpha) = s\alpha, \quad b(\alpha) = b(1-\alpha) \\ s.t. 0 < b < 1, \quad 0 < \alpha < 1, \quad s > 0, \quad \alpha \in [0, 1] \quad (10)$$

It should be noted that the output price p in the preceding analysis is assumed to be exogenous; in the following analysis, this condition needs to be relaxed, i.e. the price needs to be endogenous.

² To simplify the analysis, this paper assumes that the discount factor is 0, and it does not consider the running cost of the machines. It should be noted that taking the machine running cost into account would merely increase the complexity of calculation and analysis but not change the main findings of this paper.

³ The comprehensive calculation process will be provided upon request from the authors.

Again, following the analysis of Xepapadeas and de Zeeuw (1999), we assume that there are two manufacturing enterprises that operate in different administrative regions but compete in the same industry or market,⁴ and firm R is regulated by environmental technical standards, and firm U not. In reality, due to decentralization in the environmental regime and unbalanced development among regions, manufacturing enterprises located in different regions are often affected by environmental policies with different regulatory forces. For example, the 2013 air pollution control policies imposed much stricter requirements on companies in the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta regions. In this sense, the two companies in the model can also be understood as two types of companies that are subject to environmental regulations of different enforcement degrees. The market demand function can be simplified as:

$$p = \bar{p} - Q^R - Q^U \quad (11)$$

In Equation (11), for the sake of convenience, this paper normalizes the potential purchasing power $\bar{p}$ of the product market to 1⁵ (Xu *et al.*, 2016). We then calculate the average machine age g^R , pollution emission intensity θ^R and productivity f^R of firm R which is regulated by environmental technical standards. Further, we explore the first-order partial derivatives⁶ of the above variables concerning environmental technical standards δ , and arrive at the below:

$$\frac{\partial g^R}{\partial \delta} < 0; \quad \frac{\partial \theta^R}{\partial \delta} < 0; \quad \frac{\partial f^R}{\partial \delta} > 0$$

Based on the above analysis, this paper contends that driven by environmental technical regulations, manufacturing enterprises can simultaneously reduce pollution emission intensity while improving productivity. The key to improving productivity lies in capital renewal, and to reducing pollution emission intensity lies in both end-of-pipe treatment and capital renewal. On the one hand, propelled by environmental technical standards, manufacturing enterprises must install pollution filtration facilities with a certain processing capacity to reduce pollution emission per unit of output. On the other hand, to compensate the additional costs incurred from non-productive end-of-pipe treatment, companies tend to reduce their production scale and decrease the stock of machines on the production line. Old machinery and equipment are more susceptible to cost changes due to lower production efficiency, and their stock level tend to decline more rapidly compared with the new ones. As a result, enterprises tend to deploy new machinery and equipment, that is, they invest newer fixed capital in production and operation. Newer machines further enable firms to reduce pollution emission intensity while increasing the average productivity level. In short, environmental technical standards drive the green transition of manufacturing enterprises by promoting technological transformation in pollution control and production processes, which leads to emission reduction and efficiency improvement.

A typical case buttressing the above analysis is the transformation of China's paper industry. For a long time, the production scale of the paper industry was small, and the production technologies and equipment were backward (Chen, 2009). Many small paper mills relied on imported obsolete pulp and paper equipment for production, which resulted in serious water pollution problems. Following the State Council's National Total Pollutant Emission Control Plan during the 11th Five-Year Plan Period issued in 2006, which stressed to "vigorously promote cleaner production in key industries such as power generation, metallurgy, building materials, chemical industry, paper-making, textile printing and dyeing, and food and brewery," and the release of corresponding industry standards for cleaner production, China's paper industry eliminated more than 10 million tons of outdated production capacity and shut down more than 2,000 companies with high energy consumption and pollution levels in the period of

⁴ The number of enterprises will not change the main findings of this paper, but only increase the computational complexity. Therefore, only two enterprises are considered.

⁵ In reality, when social productivity and residents' income level improve, the purchasing potential of the product market often expands.

⁶ The corresponding calculation process and numerical simulation will be provided upon request from the authors.

the 11th Five-Year Plan. The discharge of chemical oxygen demand (a main indicator of wastewater pollutants) dropped from around 1.6 million tons in 2005 to about 950,000 tons in 2010, a decrease of more than 40%. The emission intensity of chemical oxygen demand plummeted from 0.07 ton/10,000 yuan to 0.02 ton/10,000 yuan, a decrease of more than 70%. At the same time, the paper industry accelerated the pace of industrial restructuring and technological transformation, with investment in technological transformation of equipment reaching more than 5 billion yuan. According to the data from the National Bureau of Statistics, from 2006 to 2009, the overall investment in the papermaking and paper products industry totaled 372.9 billion yuan and registered an average annual growth rate of over 20%.

3. Empirical Design

3.1 Sample Grouping and Difference-in-Differences Model Construction

Considering that cleaner production standards (CPS) exert high environmental technical requirements on enterprises in the concerned industries,⁷ they are a type of environmental policy based on technical standards as explicated in the above analysis. Hence, in the empirical analysis, we purport to verify the theoretical analysis results by taking the first implementation of the CPS in 2003 and evaluating the effect of the policy shock. Concretely, building on the empirical framework of Jiang and Lu (2018), Chen and Wan (2019), we construct a fixed-effect difference-in-differences (DID) model to quantitatively evaluate the environmental and economic performance of CPS, as well as examine the green transition of manufacturing enterprises regulated by environmental technical standards from the dimensions of emission reduction and efficiency improvement. The benchmark regression equation is set as follows:

$$emission_{it} = \alpha_0 + \beta_1 did_{it} + \theta X_{it} + \mu_i + \gamma_{ind4} + \lambda_{jt} + \varepsilon_{it} \quad (12)$$

$$tfp_{it} = \alpha_0 + \beta_1 did_{it} + \theta X_{it} + \mu_i + \gamma_{ind4} + \lambda_{jt} + \varepsilon_{it} \quad (13)$$

Where, the subscript i represents the enterprise, and $emission_i$ and TFP_i are the emission intensity and total factor productivity of firm i , respectively. Pollution emission intensity mainly includes chemical oxygen demand (cod) and industrial sulfur dioxide emission (SO_2) per unit of gross output value. Total factor productivity tfp_{op} and tfp_{lp} are calculated based on the methods of Olley and Pakes (1996) and Levinsohn and Petrin (2003), respectively. μ_i is the firm fixed effect to control for firm characteristics that do not change with time, and λ_{jt} is the two-digit industry-year fixed effect to control for the exogenous shocks at the two-digit industry level over time. Considering that more than a quarter of the firms in the sample period moved across industries at the four-digit industry level, the regression also adds the four-digit industry fixed effect γ_{ind4} . ε_{it} is a random disturbance item. Standard errors in the regression are clustered to the four-digit industry level.

In selecting the control variables X_{it} , we reference to the practice of Long and Wan (2017) and control for firm characteristics including the age of the firm (age), exports ratio ($export$), state-owned background (soe), size of the firm ($size$), subsidy ($subsidy$), and the asset-liability situation ($debt_ratio$). Further, the Herfindahl index (hhi_{ind4}) which reflects the degree of market competition in the industry is controlled in the regression to reduce the potential interference of the market structure at the four-digit industry level on the estimated results.

The DID variable did_{it} is the core independent variable. The key to constructing this variable lies in appropriately grouping samples to identify policy implementation differences at the firm level. This paper sets $did_{it}=1$ when the four-digit industry to which firm i belongs implements CPS in year t ;

⁷ The institutional background of cleaner production standards will be provided upon request from the authors.

otherwise, $did_{it}=0$. In defining the samples for the treatment group and the observation period, this paper has the following considerations: (1) It has to be noted that there may be sample selection problems due to market withdrawal of some enterprises during the CPS implementation,⁸ as well as problems with policy expectations considering that the CPS examined in this paper were implemented successively, that is, the policies implemented in the first year (2003) were more compelling than those implemented in the subsequent years.⁹ (2) This paper mainly examines large-scale, capital-intensive enterprises, this means even if the enterprise intends to exit the market, it will take them some time to deal with fixed assets such as production equipment and workshops. Based on these considerations, this paper sets the sample observation period till 2006, and the samples for the treatment group consist of enterprises in three four-digit industries¹⁰ which implemented CPS for the first time in 2003. The observation period after the CPS implementation is only 3 years, making the probability of exit within this period rather low. Therefore, the DID variable $did_{it} = treat_i \times post$. Other advantages of ending the observation period in 2006 include evading possible interferences of other events and policies, such as the subsequent financial crisis and the 11th Five-Year Plan to eliminate outdated production capacity, as well as avoiding problems such as the poor quality of industrial and enterprise data and the lack of key indicators in the subsequent years.¹¹

3.2 Data Sources and Processing

The basic data used for the regression in this paper are from the 1998-2006 Chinese Industrial Enterprises database and the Chinese Industrial Pollution Sources from Major Monitored Enterprises database, as well as the patent database of the China Intellectual Property Office published by He *et al.* (2018). Among them, the Chinese Industrial Pollution Sources from Major Monitored Enterprises database covers enterprises in the “Environmental Statistical Report System” of the Ministry of Ecology and Environment, which is the most comprehensive and reliable micro-environment database in China (Wang *et al.*, 2020). Since the 1980s, the Ministry of Ecology and Environment (Ministry of Environmental Protection before 2018) has been carrying out regular surveys nationwide on major industrial pollution producers whose pollutant emissions accounted for more than 85% of the total annual emissions in each region (Zhang *et al.*, 2018). The database records the details of the polluting enterprises’ energy and resource consumption such as coal, oil, natural gas and water, and the discharge of industrial waste gas and wastewater (e.g. sulfur dioxide, nitrogen oxides, soot, chemical oxygen demand and ammonia nitrogen), as well as the amount of investment in treatment facilities. This database has been the very basis for the calculation and compilation of environmental statistical indicators in the *China Statistical Yearbook on Environment* and *China City Statistical Yearbook*, but it only caught the attention of academia very recently.

We matched the first two databases based on corporate codes, and for the outliers, we performed a second matching based on enterprise names + administrative codes. As there was a change in national economic industry code in 2002, we aligned the four-digit industry codes from 1998 to 2002 with

⁸ For example, some companies may be unwilling or unable to implement CPS due to cost and other reasons and may withdraw from the respective market. In other words, enterprises that remain in the market after implementing CPS may have higher productivity and lower pollution emission intensity to start with.

⁹ In contrast, CPS released and implemented after 2013 are more likely to have the policy expectation effect, that is, prior to the implementation, enterprises may already be informed and make decisions accordingly, such as adjusting production capacity, changing to another industry or retreating from the market.

¹⁰ They are petroleum refining industry (2511), coking industry (2520) and tanning industry (pig leather) (1910). China issued 8 CPS on October 1, 2016 and 2 more on December 1, 2006, but since these policies took place in the second half of the year, leaving companies little time to respond in the same year. Therefore, for these companies, did_{it} is always set to 0 (Long & Wan, 2017). Also, the implementation of CPS relies on the supervision and guidance of local governments, which need some time to prepare. Hence, the above consideration is reasonable. This paper also omitted this part of the sample in regression and found that it did not affect the estimated results.

¹¹ The valid data for the core mechanism variables of this paper, i.e. productive and non-productive fixed asset investment ($mfix$ and $nfix$) end in 2006.

subsequent editions. In terms of data processing, referencing to the methods of Brandt *et al.* (2012) and Nie *et al.* (2012), we performed cross-identifications on the same enterprise based on information such as the corporate code, enterprise name, legal representative, phone number and zip code. We deleted those companies with less than 8 employees, and those whose net value of current assets or fixed assets was greater than the total assets, whose accumulated depreciation was less than the current depreciation, whose asset-liability ratio was less than 0, whose founding year was greater than the statistical year, and whose salary, value-added tax, and financial expenses were negative. In addition, we omitted those with missing key indicators such as paid-in capital, founding year, export delivery value, sales value, number of employees, fixed assets, subsidy income, total assets, and total liabilities.

In addition, considering that within the same observation period, the National Development and Reform Commission issued a similar cleaner production evaluation index system in some industries, to avoid the interference of this policy, we further removed the enterprises in the four-digit industries that implemented this index system within the observation period. Finally, this paper restricted the sample to manufacturing enterprises, resulting in a total of 215,812 observations from 1998 to 2006.¹²

4. Benchmark Regression Results

4.1 Analyzing the Benchmark Regression Results

The benchmark regression results are shown in Table 1. Columns (1) and (2) report the impact of the CPS implementation on the emission intensity of chemical oxygen demand and sulfur dioxide of manufacturing enterprises, and show that the estimated coefficients of the DID variable *did* are significantly negative. Columns (3) and (4) report the regression results on total factor productivity, and show that the estimated coefficients of *did* are significantly positive. In general, the implementation of CPS was conducive to restraining the pollution emission intensity of manufacturing enterprises while improving their productivity levels. Compared with the manufacturing enterprises that did not implement CPS in the same industry, those that implemented on average reduced the emission intensity of chemical oxygen demand and sulfur dioxide by 1.8445 and 0.3176 units respectively. In other words, for every 1,000 yuan of total output value created, 1.8445 kilograms of chemical oxygen demand and 0.3176 kilograms of sulfur dioxide were reduced in those companies; meanwhile, total factor productivity increased by 26.55% to 29.81%, respectively. These findings provide preliminary evidence for the assumptions in the theoretical analysis.

The above regression results demonstrate that the implementation of CPS can promote the green transition of manufacturing enterprises from two dimensions: Emission reduction and efficiency enhancement. We argue that this policy effect is realized mainly because implementing CPS can effectively bolster the enthusiasm of manufacturing enterprises for energy conservation and emission reduction. In addition to stimulating end-of-pipe treatment, CPS as a type of environmental technical regulation can incentivize enterprises to prevent pollution at the front end, not only through cleaner production processes, but also by using greener energy and making greener products. We postulate that driven by the environmental regulations, manufacturing companies may begin to re-examine their production processes, and look for ways to turn waste into secondary materials, reduce disposal costs and improve resource utilization. In this process, enterprises may accelerate capital renewal, that is, replacing old equipment of high energy consumption and high pollution levels with new equipment, thereby improving energy efficiency and optimizing energy utilization structure. However, this hypothesis needs to be tested empirically.

¹² The descriptive statistics of the main variables used in the regression of this paper will be provided upon request from the authors.

Table 1: Benchmark Regression Analysis

Variable	<i>cod</i>	<i>so₂</i>	<i>tfp_{op}</i>	<i>tfp_{lp}</i>
	(1)	(2)	(3)	(4)
<i>did</i>	-1.8445*** (0.0298)	-0.3176*** (0.0584)	0.2355*** (0.0110)	0.2609*** (0.0144)
<i>soe</i>	0.0427 (0.0418)	0.1679*** (0.0602)	-0.0619*** (0.0121)	-0.0370*** (0.0132)
<i>size</i>	-0.1093*** (0.0399)	-0.2473*** (0.0329)	-0.2297*** (0.0189)	0.0219 (0.0194)
<i>age</i>	0.0151 (0.0413)	-0.0027 (0.0183)	0.0041 (0.0048)	0.0307*** (0.0055)
<i>export</i>	-0.2042* (0.1095)	-0.2684*** (0.0832)	0.0359 (0.0254)	0.0823*** (0.0258)
<i>subsidy</i>	-0.0558** (0.0270)	-0.0942** (0.0429)	0.0193* (0.0100)	0.0401*** (0.0104)
<i>debt_ratio</i>	0.1046 (0.0667)	0.2970*** (0.0671)	-0.2633*** (0.0206)	-0.2786*** (0.0229)
<i>hhi_{ind4}</i>	0.0027 (0.0060)	0.0008 (0.0073)	-0.0023 (0.0015)	-0.0037** (0.0017)
Enterprise-fixed effect	Yes	Yes	Yes	Yes
Four-digit industry-fixed effect	Yes	Yes	Yes	Yes
Two-digit industry-year fixed effect	Yes	Yes	Yes	Yes
Observation value	187,399	188,332	188,670	188,670
Adjusted R ²	0.6988	0.5951	0.6676	0.7421

Note: In parentheses are robust standard errors clustered to four-digit industries. *, ** and *** denote significance at 10%, 5% and 1%, respectively. The firm fixed effects, four-digit industry fixed effects, and four-digit industry-year fixed effects are uniformly added to the regression. This applies to the following tables.

Source: Authors' calculation.

4.2 Dynamic Effect Test

To examine the dynamic processing effect of the implementation of CPS over time and further verify the hypothesis of parallel trend of the DID model, this paper draws on the event study method proposed by Jacobson *et al.* (1993) for regression analysis. The models are set as follows:

$$emission_{it} = \alpha_0 + \sum_{k=-5, k \neq -1}^{k=3} \delta_k D_{it}^k + \theta X_{it} + \mu_i + \gamma_{ind4} + \lambda_{jt} + \varepsilon_{it} \quad (14)$$

$$tfp_{it} = \alpha_0 + \sum_{k=-5, k \neq -1}^{k=3} \delta_k D_{it}^k + \theta X_{it} + \mu_i + \gamma_{ind4} + \lambda_{jt} + \varepsilon_{it} \quad (15)$$

Where, the dummy variable D_{it}^k indicates firm i in year t is in the k th year before/after the implementation of CPS in its industry. f_i be the year in which CPS was implemented in this four-digit industry to which firm i belongs. If $t - f_i = k$, then $D_{it}^k = 1$, otherwise it is 0. Where $k = -5, -4, -3, -2, 0, 1, 2, 3$. The regression equations (14) and (15) omitted the dummy variables when $k = -1$. Therefore, $\{\delta_k\}$ captures the results of the treatment group and the control group before and after the implementation of CPS.

Table 2 reports the dynamic effect of the implementation of CPS on the pollution emission intensity and productivity of the enterprises. Before the implementation, there was hardly any difference between the enterprises in the treatment group and the control group in terms of pollution emission intensity and productivity at the statistical level of 5%. But there was clearly a divergence in the dependent variables after the implementation of CPS. Compared with the enterprises in the control group, the pollution emission intensity of the enterprises in the treatment group decreased significantly while the productivity increased after the implementation of CPS, and the effect of the policy became more pronounced over

Table 2: Dynamic Effect Test

Variable	<i>cod</i>	<i>so₂</i>	<i>tfp_{op}</i>	<i>tfp_{lp}</i>
	(1)	(2)	(3)	(4)
D^{-5}	0.6619* (0.3782)	-0.0444 (0.2001)	0.0007 (0.0397)	-0.0120 (0.0476)
D^{-4}	0.3911 (0.2882)	0.0766 (0.1561)	0.0196 (0.0438)	0.0008 (0.0438)
D^{-3}	0.3187 (0.2321)	0.0361 (0.1350)	0.0003 (0.0365)	-0.0212 (0.0360)
D^{-2}	0.0612 (0.1341)	-0.0280 (0.0650)	-0.0452* (0.0253)	-0.0478** (0.0233)
D^0	-1.1650*** (0.1658)	-0.2242** (0.0946)	0.1688*** (0.0253)	0.1904*** (0.0264)
D^1	-1.8644*** (0.1794)	-0.3050*** (0.1083)	0.2073*** (0.0275)	0.2056*** (0.0291)
D^2	-1.9360*** (0.1740)	-0.3953*** (0.1011)	0.2254*** (0.0304)	0.2626*** (0.0312)
D^3	-2.0126*** (0.1726)	-0.4820*** (0.0993)	0.3748*** (0.0307)	0.3848*** (0.0319)
Observation value	187,399	188,332	188,670	188,670
Adjusted R ²	0.6990	0.5951	0.6676	0.7421

Source: Authors' calculations.

time. In short, the above results support the hypothesis of parallel trend of the DID model.

4.3 Robustness Test

In order to test the robustness of the benchmark regression results, this paper proceeds with the following¹³: (1) Replace the dependent variables; (2) omit companies that change across industries; (3) control the impact of tariffs at the industry level; (4) exclude companies that joined or exited the industry shortly before/after the CPS implementation; (5) change the measurement method of pollution emission intensity; (6) control for the time trend of pollution emission intensity at the industry level; (7) control for the linear time trend of the treatment group; (8) use the observation samples from 1998 to 2012; (9) use the propensity score matching-based DID (PSM-DID) estimates; and (10) take the industries that issued CPS at a later stage as the control group. After taking these measures, we found that the estimated coefficient signs and significance levels of the DID variables remained generally unchanged, which further supports the robustness of the benchmark regression results.

5. Mechanism Examination

The previous theoretical analysis suggests that pressured by strict environmental technical standards, manufacturing enterprises opt for technological transformation on the production side to achieve a green transition. To be specific, they will, on the one hand, increase investment in non-productive end-of-pipe treatment (e.g. installing pollution filtration equipment), and on the other hand, introduce more advanced and environmentally friendly machinery and equipment in the production process. In other words, they will speed up the pace of productive capital renewal to reduce pollution emission intensity and increase production efficiency. To this end, we further examine the impact of the implementation of CPS on the

¹³ The detailed robustness test results and analysis will be provided upon request from the authors.

Table 3: Impact of CPS Implementation on Enterprises' End-of-pipe Treatment Performance

Variable	<i>airequip</i>	<i>so₂equip</i>	<i>aircap</i>	<i>so₂cap</i>	<i>waterequip</i>	<i>watercap</i>
	(1)	(2)	(3)	(4)	(5)	(6)
<i>did</i>	0.1085*** (0.0089)	0.0162*** (0.0054)	1.0337*** (0.0200)	0.0292** (0.0136)	-0.0189** (0.0078)	1.5573*** (0.1154)
Observation value	185,294	118,090	128,160	117,840	184,632	184,707
Adjusted R ²	0.7631	0.6836	0.7221	0.6050	0.7543	0.7917

Source: Authors' calculations.

end-of-life treatment and capital renewal of manufacturing enterprises.

5.1 End-of-Pipe Treatment

In order to test the mechanism of end-of-pipe treatment, this paper examines the impact of the implementation of CPS on the enterprises' investment in waste gas and wastewater treatment facilities. The corresponding regression results are reported in Table 3. Columns (1) and (2) show that after the implementation of CPS, the number of facilities to treat industrial waste gas (*airequip*) and sulfur dioxide (*so₂equip*) experienced an increase of 11.46% and 1.63%, respectively. When focusing on the treatment capacity of the facilities, the hourly treatment capacity of industrial waste gas and sulfur dioxide (*aircap* and *so₂cap*) increased by 181.14% and 2.96%, respectively. Columns (5) and (6) show that the implementation of CPS significantly increased enterprises' daily treatment capacity of industrial wastewater (*watercap*) but reduced their investment in treatment facilities (*waterequip*). The above regression results suggest that driven by strict environmental technical standards, manufacturing enterprises have significantly increased investment in end-of-pipe treatment, and they seemed to opt for using more technologically advanced pollution control facilities instead of merely increasing the number of facilities. Overall, the above results testify the mechanism of end-of-pipe treatment.

5.2 Capital Renewal

To test the mechanism of capital renewal, we replace the dependent variables in the benchmark regression model with various indicators that reflect an enterprise's capital renewal situation, including investment, depreciation, capital productivity and pollution production intensity. The corresponding regression results are shown in Table 4 and Table 5.

(1) Investment, depreciation, and capital productivity. Columns (1)-(3) of Table 4 report the regression results on investment indicators. Clearly, the total investment in fixed assets (*inv*) of the treated enterprises increased significantly after implementing CPS. When further dividing the total investment in fixed assets into investment for production and operation purposes and for non-production and non-operation purposes (*mfix* and *nfix*), we found that CPS mainly stimulated investment for the former purposes, which had an overage increase of 16.53%. The regression results in Column (4) show that after the implementation of CPS, the depreciation (*depre*) of the enterprises in the same year increased by 34.19%. The regression results in Column (5) show that when the depreciation rate is used as a proxy variable for capital renewal, the implementation of CPS accelerated the depreciation rate (*depre_{-rate}*) by 1.8083%, further supporting the theoretical assumption that environmental technical standards help accelerate capital renewal of manufacturing enterprises. The regression results in Column (6) show that after implementing CPS, the capital productivity (*kefficiency*) of the treated enterprises increased significantly, with an average growth of about 2.78%.

(2) Pollution production intensity. Table 5 reports the impact on the intensity of wastewater and major air pollutants produced by the companies. Compared with pollution emission intensity, the

Table 4: Impact of CPS Implementation on Investment Behavior of Enterprises

Variable	<i>inv</i>	<i>mfix</i>	<i>nfix</i>	<i>depre</i>	<i>depre_{-rate}</i>	<i>kefficiency</i>
	(1)	(2)	(3)	(4)	(5)	(6)
<i>did</i>	0.5122*** (0.0245)	0.1530*** (0.0204)	0.1154 (0.0949)	0.2941*** (0.0107)	1.8083*** (0.0541)	0.0274*** (0.0016)
Observation value	122,317	90,492	38,050	180,036	193,721	188,813
Adjusted R ²	0.7243	0.6803	0.4485	0.8161	0.2737	0.9970

Source: Authors' calculations.

Table 5: Impact of CPS Implementation on Enterprises' Pollution Production Intensity

Variable	<i>pcod</i>	<i>pandan</i>	<i>ps_{o2}</i>	<i>ps_{oot}</i>	<i>pdust</i>
	(1)	(2)	(3)	(4)	(5)
<i>did</i>	-2.5025*** (0.2291)	-0.0074*** (0.0025)	-0.3917*** (0.0786)	-0.6936*** (0.1332)	0.5167 (0.4288)
Observation value	179,814	117,358	176,603	181,744	174,775
Adjusted R ²	0.6889	0.4762	0.5946	0.4465	0.7243

Source: Authors' calculations.

change in pollution production intensity reflects the emission of the manufacturing enterprise during the production process, which is directly related to its production technology, but hardly affected by end-of-pipe treatment. Therefore, examining this indicator can reveal the impact of capital renewal while avoiding the interference of the end-of-pipe treatment mechanism. The regression results in Columns (1) and (2) show that the implementation of CPS was associated with reduced production intensity of chemical oxygen demand and ammonia nitrogen (*pcod* and *pandan*), with a decrease by 2.5025 and 0.0074 units, respectively. Furthermore, the production intensity of sulfur dioxide and soot (*ps_{o2}* and *ps_{oot}*) of the enterprises in the treatment group decreased significantly, except that of dust (*pdust*). The results are consistent with the changes in the emission intensity of each pollutant as shown in the benchmark regression and robustness tests.

In general, after implementing CPS, manufacturing enterprises accelerated their investment and depreciation, and purchased more advanced and environmentally friendly production equipment. Compared with the companies which were not influenced by the CPS policies, they experienced a higher level of capital productivity and a lower level of pollution production per unit of output value. This result supports the mechanism of capital renewal.

5.3 Utilization Efficiency and Structure of Energy and Resources

In the theoretical model, for the simplicity of the analysis, we did not consider the utilization of energy resources in the production process. However, in practice, fossil fuels such as coal, oil and natural gas and water resources are important inputs for production, and their utilization efficiency directly affects the level of productivity. Research has suggested that a company's energy efficiency and structure are closely related to its pollution emission level (Shi & Li, 2020). To this end, we further examine the impact of the implementation of CPS on the utilization efficiency and structure of energy and resources in manufacturing enterprises. The corresponding regression results are shown in Table 6.

Columns (1)-(3) of Table 6 report the impact of the implementation of CPS on enterprises' fossil energy consumption intensity. Column (1) shows that the estimated coefficient of the overall fossil energy consumption intensity (*energy*)¹⁴ is significantly negative. Given that coal is the most important fossil energy input in China's industrial sector, Column (2) further reports the impact on the total coal consumption intensity (*coal*) and shows that the regression coefficient is still negative, albeit at a weaker level of significance. When focusing on the consumption intensity of fuel coal mainly used as boiler fuel (f_{coal}), the estimated coefficient of the DID variable is significant at the level of 1%. The estimated coefficient for freshwater consumption intensity (f_{water}) shown in Column (4) is also significantly negative. The above results suggest that the implementation of CPS significantly improved the utilization efficiency of fossil energy and water resources in manufacturing enterprises.

Columns (5) and (6) report the impact of CPS on the utilization structure of energy and resources in manufacturing enterprises. In terms of energy utilization structure, due to the lack of data concerning the utilization of new energy, this paper measured the utilization rate of clean energy by calculating the proportion of relatively clean natural gas (*clean*) in the total fossil energy consumption (Han *et al.*, 2020). In terms of water utilization structure, this paper used the proportion of recycled water consumption (*recycled*) in the total industrial water consumption to measure the water recycling rate of the enterprise. The estimated coefficient of the clean energy utilization rate as shown in Column (5) is significantly positive, so is the recycled water rate as shown in Column (6), indicating that CPS not only propelled manufacturing enterprises to improve the utilization efficiency of energy and resources, but also drove them to use cleaner energy and increase the resource recycling rate.

In short, the above regression results suggest that pressured by strict environmental technical standards, manufacturing enterprises have the propensity to increase investment in end-of-pipe treatment and capital renewal, while also optimizing the utilization efficiency and structure of energy and resources. Although the latter result has not been captured in the above theoretical analysis, this does not nullify the theoretical analysis results. When manufacturing enterprises accelerate capital renewal, that is, purchase more advanced and environmentally friendly production, they often concurrently improve the utilization efficiency and optimize the utilization structure of energy and resources, given that the input level and the type of energy and resources used in the industrial production process largely depend on the production equipment. In other words, we can conclude that due to environmental

Table 6: Impact of CPS Implementation on Utilization Efficiency and Structure of Energy and Resources

Variable	Utilization efficiency of energy and resources				Utilization structure of energy and resources	
	<i>energy</i>	<i>coal</i>	f_{coal}	f_{water}	<i>clean</i>	<i>recycled</i>
	(1)	(2)	(3)	(4)	(5)	(6)
<i>did</i>	-0.0064*** (0.0017)	-0.0035* (0.0019)	-0.0056*** (0.0018)	-1.5054*** (0.0570)	0.5700*** (0.0891)	2.4371*** (0.2509)
Observation value	111,907	130,570	185,205	192,092	91,634	176,400
Adjusted R ²	0.7297	0.7493	0.5283	0.7230	0.7999	0.7182

Source: Authors' calculations.

¹⁴ The calculation steps of the overall fossil energy consumption intensity are as follows: Based on the reference coefficients for converting various energy sources into standard coal in the 2020 China Energy Statistical Yearbook, convert the coal, fuel oil and natural gas consumption of the enterprise into standard coal respectively, and then, the energy consumption of each item whose heat units are unified is summed up and divided by the total output value.

technical standards, companies' capital renewal is directly associated with the improvement of utilization efficiency and structure of energy and resources, thereby verifying the mechanism of capital renewal.

5.4 Technological Innovation

The analysis thus far examined that driven by environmental technical standards, manufacturing enterprises took a green transition path of technological transformation underpinned by end-of-pipe treatment and accelerated capital renewal, which further improved the utilization efficiency and structure of energy and resources. However, in addition to this incremental path of technological advancement, we assume that manufacturing enterprises may also choose a more direct and radical path, namely technological innovation. To this end, we further examine the impact of the implementation of CPS on technological innovation of manufacturing enterprises. The corresponding regression results are presented in Columns (1)-(4) of Table 7. The results in Column (1) show that the implementation of CPS had no significant impact on the ratio of new product output value (*newper*), and Column (2) shows that CPS did not significantly increase the number of patent applications (*patents*).

In order to further investigate the impact of CPS on enterprises' green technology innovation, this paper identified the number of green patent applications of each company (including patents for green invention and green utility model) based on the "International Patent Classification Green List" launched by the World Intellectual Property Organization (WIPO) in 2010, as well as the international patent classification number (Xu & Cui, 2020). Columns (3) and (4) report the regression results on the number of applications for green patent (*patent_{gre}*) and for green invention patent (*green_{inv}*), respectively, and show that the estimated coefficients of the DID variables are not significant. This result suggests that even pressured by strict CPS, technological innovation may not be the primary path for manufacturing enterprises to achieve a green transition.

This probably is because technological innovation requires a certain amount of technology accumulation, and its investment return is long term and has great uncertainty (Minetti *et al.*, 2015), whereas CPS is a command-and-control environmental regulation method which requires companies to comply within a short period (otherwise they may face fines or risk being shut down). Therefore, companies opt to choose a more effective means to reduce emission, that is, a technological transformation path tackling emission during and at the end of the production process (Gao & Yuan, 2020). This may also be the reason why empirical studies have failed to account for the direct impact of environmental regulation on technological innovation (Fan *et al.*, 2019).

It should be noted that even when an enterprise steps up investment in innovation, it is perhaps unrealistic to convert the innovation input into innovation output within a short period after CPS. But the empirical samples in this paper only have an observation period of three years, and mainly innovation output variables¹⁵ are used to account for technological innovation. Therefore, the regression results shown in this paper do not deny enterprises' potential investment in technological innovation. However, considering that the effect of technological innovation measured by innovation output is at least insignificant in the short term, it cannot explain the policy effect of CPS on the green transition of manufacturing enterprises. Hence, the above regression results at least demonstrate that in the short term, CPS do not spur a green transition through technological innovation.

If technological transformation is the main mechanism for the green transition of manufacturing enterprises, we further postulate that the green technology demands of manufacturing enterprises affected by strict CPS will stimulate technological innovation of their upstream equipment manufacturing industries. To this end, we further examine after the implementation of the first CPS in 2003, whether upstream equipment manufacturing enterprises closely related to the treated industries generated more

¹⁵ Although R&D expenditure can more directly reflect the innovation investment of enterprises, these data for the samples only exist in 2005 and 2006. The lack of pre-policy observations limited its usage in the DID model in this paper.

Table 7: Impact of CPS Implementation on Technological Innovation of Enterprises

Variable	<i>newper</i>	<i>patent</i>	<i>patent_gre</i>	<i>green_inv</i>	<i>patent_gre</i>	<i>green_inv</i>
	(1)	(2)	(3)	(4)	(5)	(6)
<i>did</i>	0.1194 (0.1151)	-0.0009 (0.0020)	-0.0002 (0.0002)	-0.0002 (0.0002)		
<i>upstream_{post}</i>					0.0031 (0.0032)	0.0048* (0.0026)
Observation value	166,642	193,931	193,931	193,931	189,466	189,466
Adjusted R ²	0.6152	0.4571	0.2391	0.2224	0.2413	0.2231

Source: Authors' calculations.

green technology innovations than their peers which were unaffected by CPS.

Concretely, we first set the four-digit industries in the general equipment manufacturing industry (35) and special equipment manufacturing industry (36) which have close productive linkages with the three industries of the treatment group, i.e. the petroleum refining industry (2511), coking industry (2520) and tanning industry (pig light leather) (1910) as the upstream equipment manufacturing industry of the treatment group¹⁶ (*upstream*), which we then multiplied with the dummy variable (*post*) for years after 2003 to generate a new DID variable *upstream_{post}*, and finally, we replaced the DID variable in the benchmark regression and performed re-regression.¹⁷ The regression results in Column (5) of Table 7 demonstrate that after the implementation of the first batch of CPS in 2003, the upstream equipment manufacturing enterprises in the treated industries had a better performance in terms of green patent applications, albeit the estimated coefficient of *upstream_{post}* is not significant. When further examining the number of applications for green invention patent, we found the estimated coefficient of *upstream_{post}* is significantly positive at the level of 10%.¹⁸ This shows that although CPS did not directly induce green technology innovation in enterprises in the treated industries, it indirectly promoted green technology innovation in the upstream equipment manufacturing enterprises, which offered enterprises in the treated industry production and pollution treatment equipment with advanced green technologies, and ultimately enabled them to achieve a green transition. This finding indirectly confirms the Porter hypothesis.

6. Heterogeneity Analysis

According to the above analysis, driven by CPS, manufacturing enterprises may attempt to achieve a green transition predominantly by taking a more incremental path of technological transformation for end-of-pipe treatment and capital renewal. This means that the effect of the green transition mainly depends on the degree of technological transformation, which is directly constrained by the urgency and financing capability of the enterprise. On the one hand, manufacturing enterprises with a high pollution level and backward production technologies are expected to have relatively high demands

¹⁶ The specific industry definitions will be provided upon request from the authors.

¹⁷ The treatment group in the regression includes upstream equipment manufacturing enterprises (i.e. *upstream*=1) in the three industries of petroleum refining, coking industry and tanning industry (pig leather), and the control group include those upstream equipment manufacturing enterprises in industries (i.e. *upstream*=0).

¹⁸ Many manufacturing enterprises in the treated industries choose to purchase production equipment and pollution control equipment from abroad (which promotes the green technology innovation in foreign upstream equipment manufacturing enterprises). Due to data limitations, the regression in this paper only investigated the green technology innovation effect on domestic upstream equipment manufacturing enterprises, which might have undermined its effect.

for technological transformation since they face far deviation from the CPS-imposed environmental requirements, whereas those companies with relatively fast capital renewal have less urgency since their production technologies are already more advanced. On the other hand, companies with high expected profitability have more internal cash flow and are more likely to obtain bank loans, hence they are better positioned to raise funds for technological transformation. To verify the assumptions, this paper first captured the technological transformation needs and financing capabilities of companies before 2003 using data on average pollution emission intensity, productivity level, depreciation rate and main business profit level,¹⁹ and then captured the potential heterogeneous policy effects by incorporating the multiplication of these pre-policy, non-time-varying enterprise characters with DID variables into the benchmark regression.

Tables 8 and 9 report the heterogeneity test results, where, Columns (1)-(4) of Panel A and Panel B in Table 8 respectively use the mean values of enterprises' chemical oxygen demand and sulfur dioxide emission intensity before 2003 as the regression results of the multiplicative variables. The results show that enterprises with higher chemical oxygen demand and sulfur dioxide emission intensity experienced a

Table 8: Heterogeneity Test 1

Variable	<i>cod</i>	<i>so₂</i>	<i>tfp_{op}</i>	<i>tfp_{lp}</i>
	(1)	(2)	(3)	(4)
Panel A: Multiplicative variable $\bar{x}$ is the <i>cod</i> mean value of the enterprises before policy implementation				
<i>did</i> × $\bar{x}$	-0.6417*** (0.0815)	-0.0744 (0.0750)	0.0128*** (0.0042)	0.0140** (0.0055)
<i>did</i>	0.5105* (0.2620)	-0.0281 (0.2417)	0.1750*** (0.0171)	0.1953*** (0.0223)
Observation value	153,009	153,242	151,061	151,061
Adjusted R ²	0.6937	0.5885	0.6538	0.7424
Panel B: Multiplicative variable $\bar{x}$ is the <i>so₂</i> mean value of the enterprises before policy implementation				
<i>did</i> × $\bar{x}$	-0.0566*** (0.0151)	-0.7963*** (0.0164)	0.0224*** (0.0046)	0.0268*** (0.0049)
<i>did</i>	-1.8057*** (0.0304)	0.2598*** (0.0422)	0.2077*** (0.0126)	0.2296*** (0.0171)
Observation value	153,009	153,242	151,061	151,061
Adjusted R ²	0.6921	0.5912	0.6539	0.7424
Panel C: Multiplicative variable $\bar{x}$ is the <i>tfp_{op}</i> mean value of the enterprises before policy implementation				
<i>did</i> × $\bar{x}$	0.0287 (0.0824)	0.5571** (0.2425)	-0.2858*** (0.0406)	-0.2427*** (0.0453)
<i>did</i>	-1.9206*** (0.1648)	-1.3750*** (0.4825)	0.7922*** (0.0822)	0.7312*** (0.0933)
Observation value	152,048	152,293	150,752	150,752
Adjusted R ²	0.6918	0.5874	0.6543	0.7429

Note: The multiplicative variable does not change with time, so it will be absorbed by the firm fixed effect. Due to the lack of observations before 2003 in some enterprises, the sample size of the regression in the heterogeneity test is smaller than that in the benchmark regression. The same applies to Table 9.

Source: Authors' calculations.

¹⁹ The advantage of using a pre-determined variable as a multiplicative variable is that it can avoid the interference of the policy and capture the heterogeneity effect of the policy more neatly. Considering that there may be many negative values regarding the profit level of the main business, taking the logarithm directly would lose sample size; hence, this paper standardized this variable by subtracting the variable from its mean value and then dividing its standard deviation.

Table 9: Heterogeneity Test 2

Variable	<i>cod</i>	<i>so₂</i>	<i>tfp_{op}</i>	<i>tfp_{lp}</i>
	(1)	(2)	(3)	(4)
Panel A: Multiplicative variable $\bar{x}$ is the <i>tfp_{lp}</i> mean value of the enterprises before policy implementation				
<i>did</i> × $\bar{x}$	0.2260 (0.1394)	0.7327*** (0.2647)	-0.1666*** (0.0367)	-0.1638*** (0.0310)
<i>did</i>	-3.3365*** (0.9051)	-5.0529*** (1.7373)	1.3112*** (0.2437)	1.3184*** (0.2055)
Observation value	152,048	152,293	150,752	150,752
Adjusted R ²	0.6918	0.5875	0.6542	0.7429
Panel B: Multiplicative variable $\bar{x}$ is the mean value of the enterprises' depreciation rate before policy implementation				
<i>did</i> × $\bar{x}$	0.0358 (0.0550)	0.0713*** (0.0159)	-0.0148*** (0.0046)	-0.0088* (0.0051)
<i>did</i>	-2.0626*** (0.3276)	-0.7350*** (0.1302)	0.3133*** (0.0297)	0.3017*** (0.0331)
Observation value	152,960	153,192	151,029	151,029
Adjusted R ²	0.6923	0.5881	0.6537	0.7423
Panel C: Multiplicative variable $\bar{x}$ is the mean value of enterprises' main business profit level before policy implementation				
<i>did</i> × $\bar{x}$	-0.0272 (0.0331)	-0.2335* (0.1335)	0.0210*** (0.0072)	0.0248*** (0.0080)
<i>did</i>	-1.8455*** (0.0282)	-0.2986*** (0.0561)	0.2225*** (0.0128)	0.2473*** (0.0172)
Observation value	153,009	153,242	151,061	151,061
Adjusted R ²	0.6921	0.5885	0.6538	0.7424

Source: Authors' calculations.

greater reduction in pollution emission intensity and a faster increase in productivity after implementing CPS. When using the ex-ante value of total factor productivity as a multiplicative variable, the regression results of Columns (1)-(4) of Panel C in Table 8 and Panel A in Table 9 show that firms with a lower productivity level prior to the policy implementation experienced higher reduction in pollution emission intensity and faster increase in productivity after the policy shock of CPS. Columns (1)-(4) of Panel B in Table 9 use the depreciation rate before 2003 to reflect enterprises' previous capital renewal rate. They show that enterprises with faster depreciation prior to the policy implementation experienced a smaller reduction in pollution emission intensity and a slower increase in productivity after the policy shock of CPS. The above regression results precisely support the logic of technological transformation needs, that is, enterprises with higher pollution emission intensity, lower productivity, and slower capital renewal rate before the policy implementation have more urgency for technological transformation due to a lower degree of compliance; and the greater the degree of technological transformation is, the more pronounced the green transition effect. When using the profit level of the main business before 2003 to represent the existing financing capacity of the enterprises, the regression results as shown in Columns (1)-(4) of Panel C in Table 9 suggest that enterprises with stronger financing abilities before the policy implementation experienced higher pollution emission intensity reduction and faster productivity increase after implementing CPS, which also supports the logic of financing capacity, that is, enterprises with stronger financing capacities prior to the policy implementation are more likely to implement technological transformation so as to achieve better green transition results. In general, the heterogeneity analysis further supports the above technological transformation mechanism.

7. Conclusion and Policy Implications

Since the 18th National Congress of the CPC, how to balance “lucid waters and lush mountains” with “gold and silver mountains” (i.e. the relation with environmental/ecological protection and economic growth) has become a hotly debated topic in the Chinese academic and industrial circles. In this paper, we introduced mandatory environmental technical standards in the model framework of Xepapadeas and de Zeeuw (1999) to examine the influence and mechanism of technical environmental regulations on the green transition of manufacturing enterprises. Furthermore, we empirically verified the theoretical analysis results using the matched samples of manufacturing enterprises from the Chinese Industrial Enterprises database and the Chinese Industrial Pollution Sources from Major Monitored Enterprises database. Overall, our study revealed that environmental technical standards are conducive to promoting the technological transformation of manufacturing enterprises, which further leads to a green transition that simultaneously benefits pollution emission intensity reduction and productivity improvement.

In the process of technological transformation, manufacturing enterprises tended for, on the one hand, strengthen end-of-pipe treatment, and on the other hand, accelerate the deployment of more advanced and environmentally friendly production equipment. Moreover, through the capital renewal method, enterprises managed to improve the utilization efficiency and consumption structure of energy and resources. Further analysis found that thanks to environmental technical standards, the technological transformation needs of the regulated enterprises indirectly promoted the green technology innovation of their upstream equipment manufacturing enterprises, pointing to the complementary effect of technological transformation and technological innovation among industries. The heterogeneity test showed that the green transition effect of environmental technical standards was more significant on enterprises with higher pollution emission intensity, lower productivity, slower capital renewal and stronger financing capacities prior to the policy implementation.

The findings of this paper have important theoretical and practical implications. On the one hand, our research shows that under the command-and-control environmental regulations represented by environmental technical standards, economic performance and environmental performance are not exclusive, rather, there is still room for reconciliation between the two. On the other hand, the research reveals that facing environmental regulations, manufacturing enterprises can choose a more incremental and pragmatic green transition, that is, technological transformation for both pollution emission control and the production process. The technological transformation also indirectly drives green technology innovation in the upstream equipment manufacturing industries. Considering that command-and-control environmental regulations are still the predominant form of environmental regulation imposed in China, and that in reality, many manufacturing enterprises lack the relevant technical accumulation and necessary financing capabilities for technological innovation, we propose the following for policy consideration:

(1) At present, environmental regulations in China are shifting from the traditional command-and-control type to a market-incentive type. In this process, we suggest that instead of completely abolishing the command-and-control type, the two forms of environmental regulation policies should be complementary and used when applicable. As we have revealed, environmental technical standards can effectively unleash the energy saving and emission reduction potential of manufacturing enterprises while improving production efficiency. Therefore, in adjusting and optimizing the environmental regulation policy system, we suggest that technical standard-type environmental regulations represented by CPS should be further promoted.

(2) Although technological innovation appears to be more “high-end” and is hailed by regulatory authorities, in reality, manufacturing enterprises are only able to respond to environmental regulations based on their own resource endowments and comparative advantages, and many of them can only

choose a more progressive technological transformation path, such as strengthening end-of-pipe treatment, accelerating capital renewal, and improving the utilization efficiency and structure of energy and resources. Hence, environmental supervision departments must reckon with and respect the reality of manufacturing enterprises and avoid unrealistic expectations of technological innovation.

(3) In order to accelerate the green transition of the manufacturing industry, governments at all levels should consider implementing policies to reduce tax for green investment in the process of ecological civilization construction. This can help companies reduce the short-term depreciation cost and pollution control cost in the process of capital renewal and end-of-pipe treatment. In addition, governments should increase fiscal and taxation support for manufacturing enterprises that are in urgent need of green technological transformation but with weak financing capabilities. To this end, we suggest that the Ministry of Ecology and Environment and the Ministry of Industry and Information Technology should jointly set up a special technological transformation fund to support and guide traditional pollution-intensive manufacturing industries in the green transition process.

(4) Since the technological transformation level of manufacturing enterprises is closely correlated with the technological innovation level of their upstream equipment manufacturing industry, in order to improve the overall technological progress level, it is necessary for the Chinese government to steer the equipment manufacturing industry towards the medium- and high-end of the global value chain. In particular, the government should foster several leading enterprises in manufacturing environmental protection equipment. We propose that relevant departments should increase fiscal, taxation and financial support for this manufacturing industry, actively develop green financial products and derivatives such as green credit, green bonds and financial leasing, and encourage social capital to invest in this industry.

Due to limitations in the research samples and the regression models, this paper only managed to examine the policy effect of implementing CPS on companies that are directly affected within a relatively short period of time. The long-term effect of the policy and how it affects other firms which are not directly hit have not been explored in this paper. Therefore, we suggest that future studies can focus on comprehensively examining the short-term and long-term policy effects of CPS while simultaneously considering both the direct and indirect effects of the policy. 

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