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Does China's Pollution Levy Standards Reform Promote Green Growth?

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Abstract: Estimating the impact of environmental taxes on economic output is of great theoretical value for promoting green growth in China. Using a dataset of 232 cities from 2004 to 2014, this paper investigates the effect of pollution levy standards reform (PSR) on green total factor productivity (GTFP). We employ directional distance functions (DDF) computed by data envelopment analysis (DEA) to derive GTFP based on the Malmquist–Luenberger (ML) productivity index. Then, we investigate the impacts of PSR on China's GTFP using Difference-in-Differences (DID) estimation. The results reveal that PSR has an inhibitory effect on GTFP, via the mechanism of technological change. Furthermore, PSR has heterogeneous impacts on different city types. The results indicate that PSR statistically significantly reduces GTFP in key environmental protection cities (KEPCs), large cities, and eastern cities, but that it has less impact on non-KEPCs, small/medium cities, megacities, and cities in central areas.

Keywords: pollution levy standards reform; green total factor productivity; DEA; Difference-in-Differences

1. Introduction

Over the past three decades, China's economy has developed rapidly and has had remarkable achievements in many fields. It is now the world's second-largest economy. However, the long-term economic growth created by an increase in factor inputs and the expansion of scales of production has brought about serious environmental problems, notably air pollution. In the 2008 Global Environmental Performance Index jointly published by Yale University and the World Economic Forum, China ranked 177th out of 180 countries and regions in air quality. In 2017, 239 of 338, or 70.7%, of Chinese cities exceeded air quality standards. A total of 36.1% of 463 Chinese cities with precipitation monitoring experienced acid rain [1]. This terrible environmental pollution has seriously weakened residents' health, decreased regional economic operational efficiency, and threatened the quality of the nation's economic development.

Faced with this serious environmental pollution, the Chinese government has undertaken a series of environmental protection policies. Looking back at Chinese environmental protection policies since the reforms and opening up in 1978, the Chinese government has primarily focused on implementing command-and-control environmental regulations. In the 21st century, market-based environmental protection policies have gradually emerged. The implementation of a pilot SO_2 emission trading policy in 2002 showed that China had begun to use market-based environmental protection policies to solve environmental problems. Environmental tax reforms are an important class of market-based environmental protection policies that have played an important role in promoting the coordinated development of the environment and the economy in recent years. However, many people are concerned that the government's strict environmental regulations may slow down China's economic growth. In theory, environmental regulations may impose additional emissions costs on companies, thereby reducing their productivity and market competitiveness. Some studies have found that the U.S. Clean Air Act, enacted in 1970, caused high structural unemployment in pollution-intensive industrial enterprises and a decline in capital stocks, economic growth rates, and total factor productivity (TFP) [2,3]. Gray and Shadbegian [4] analyzed the relationship between productivity, pollution abatement expenditures, and other measures of environmental regulation in plants across three industries, and they found that more-regulated plants had significantly lower productivity levels, and slower productivity growth rates than less-regulated plants. Compared with command-control environmental regulation, market-based measures that increased coal prices could effectively reduce coal usage and air pollution in India, but also hindered the entry of new enterprises and forced them to withdraw from the market [5]. However, the Porter Hypothesis argues that appropriate and strict environmental regulations can spur innovation, which may in turn increase firm productivity and market competitiveness [6]. Flexible environmental regulations could weaken the mediating effects of technological innovation on the relationship between environmental regulation and business performance. They could also mitigate the negative impact of environmental regulation on both technological innovation and business performance [7]. In recent years, there have been many supporters of the Porter Hypothesis [8–11].

However, the results of the research on different environmental policies may not be consistent [12]. At present, most of the literature focuses on the impact of command-and-control environmental policies on economic growth. The acid rain and SO_2 pollution control zone policies (also known as the "two control zones"), which were implemented in 1998, are the most powerful command-and-control environmental regulations in China at present. Studies have shown that the "two control zones" improved the profits and product conversion rate of export enterprises. They also promoted the TFP of pollution-intensive industrial enterprises by optimizing their industrial structure, upgrading clean technology, and eliminating high-polluting and inefficient enterprises [10,13–15]. In addition to the "two control zones," Li and Chen [16] found that the Revision of Air Pollution Prevention and Control Law (APPCL2000) significantly improved the TFP of industrial sectors that created intensive air pollution. Long and Wan [17] found that the implementation of clean production standards significantly increased enterprise profitability, but it did not promote corporate innovation or subsidies.

There is also some literature on the economic effects of market-based environmental protection policies. Some studies have found that the EU's carbon trading system has not significantly affected the income or employment of German enterprises [18]. However, some studies claim that the environmental policy represented by the emissions trading mechanism could produce huge economic dividends [19–22]. In China, Li and Shen [23] found that the emission trading system implemented in 2002 not only failed to reduce pollution, but that it caused even more pollution in the pilot areas. Tu and Shen [24] found that China's SO_2 emissions trading pilot in 2002 did not increase total industrial output in the short or long term, and it also failed to reduce pollution abatement costs [25]. Tang et al. [26] pointed out that the impact of carbon emission trading policies on economic output depended on the carbon emission authorities' allocation mechanism. At the enterprise level, Ren et al. [27] and Qi et al. [28] found that the SO_2 emissions trading pilot in 2002 significantly improved corporate TFP and green innovation. While environmental tax reform is an important approach towards market-based environmental regulations, it has not been extensively studied in the current literature. Some studies have found that pollution discharge fees cannot fundamentally solve the problem of pollution [29]. In the long term, enterprises will increase their investment in technological innovation in order to improve enterprise productivity levers. Generally, after a one-time investment in environmental protection, enterprises are exempt from paying fees or economic penalties for excessive discharge. This is because their pollution emissions meet national and local environmental standards, which reduces the economic burden on the enterprises. Zhang et al. [30] found that the expected effect of the Regulations on the Administration of the Collection and Use of Pollution Discharge Fees was not satisfactory, because it fundamentally failed to reduce pollution in China. Guo et al. [31] found that the SO_2 pollution levy standards reform (PSR) significantly reduced industrial SO_2 emissions. Lu et al. [32] and Li et al. [33] found that the PSR constrained economic growth.

Although there is a growing amount of literature on environmental regulation, there is little research on environmental tax reform. There have been few investigations in the existing literature on the impact of PSR on green total factor productivity (GTFP), especially in China. To fill this gap, this study sets out to examine whether PSR results in positive changes in regional GTFP. First, unlike Lu et al. and Li et al., who studied the impact of PSR on environmental efficiency [32,33], this paper uses directional distance function (DDF) to calculate Malmquist–Luenberger index (ML index), and study the impact of PSR on GTFP. It also discusses the direct mechanism through which PSR affects GTFP, to discern if the mechanism works through changes in efficiency or technology. Furthermore, this paper uses PSR as a quasi-natural experiment to re-examine the Porter Hypothesis and explore its mechanisms. This is the first paper to study the direct link between PSR and GTFP. Making use of Difference-in-Differences (DID) analysis, we identify the causal effects that PSR has on GTFP. By comparing the treatment and the control groups, we can better control for the effects of observable and unobservable factors, and thus identify the impact of PSR on GTFP. Finally, this paper is also significant as a reference for the recently implemented environmental protection tax.

This study is structured as follows. The second section is a brief description of the SO_2 levy standards reform in China. The third section focuses on the data description, variables selection and empirical strategy, which includes the DEA model to measure GTFP, and the DID strategy to analyze how PSR affects GTFP. The fourth section presents the empirical results. The last section represents conclusions derived from the presented research, and some policy implications can also be proposed from the empirical results.

2. A Brief Description of SO_2 Levy Standards Reform in China

Most research agrees that environmental pollution derives mainly from the externalities of economic behavior [34]; therefore, internalizing the cost of environmental pollution is the best way to solve it. With this theory in mind, countries around the world have responded by levying taxes on polluters. China's pollution levy system was first mentioned in the Report on Environmental Protection Work in 1978. Furthermore, in 1979, the Environmental Protection Law (Enforcement) clearly stipulated that pollutant discharges exceeding national standards would be fined according to their concentration and quantity. Since then, a pollution charge system has gradually been developed in various provinces. The Administration for Levy and Use of Pollution Discharge Fees promulgated by the State Council in 2003 has made major adjustments to many aspects, including levy objects, levy standards, management and use of pollution discharge fees, and the total charge system clarification [35]. Subsequently, Management Measures for Levy [36] and Use of Pollutant Discharge Fees [37] were promulgated, and the system of Pollutant Discharge Fees was comprehensively and systematically established in China [38]. Although the Administration for Levy and Use of Pollution Discharge Fees raised the SO_2 levy standard from 0.2 RMB/kg to 0.63 RMB/kg, and the levy range was extended from the two control zones to the entire country, China's current pollution levy standards are still very low. Therefore, polluters would rather pay the pollution fees than tackle pollution itself [39]. In response to this problem, the State Council issued the Comprehensive Work Plan for Energy Conservation and Emission Reduction [40] in May 2007, requiring all provinces to raise their SO_2 levy standards, doubling the SO_2 discharge fee from 0.63 RMB/kg to 1.26 RMB/kg. After the issuance of this regulation, provinces actively adjusted their SO_2 levy standards. Moreover, the Notice on Adjusting the Levy Standard of Pollution Discharge Fee [41] issued in September 2014 required all provinces to adjust their SO_2 levy standards to no less than 1.2 RMB/kg by the end of June 2015. Therefore, other provinces that had not yet changed their SO_2 emission fee adjusted their SO_2 levy standards before 2015.

This study collected detailed information on the reform of SO_2 levy standards for each province from 2007 to 2014, as shown in Table 1 (The provinces of Shanxi and Heilongjiang stipulated that only enterprises that have not completed the construction of flue gas desulfurization facilities, or whose SO_2 emissions exceeded standards, should adjust their SO_2 levy standards. Therefore, this study did not include these two provinces in the treatment group). It considers the adjustment of SO_2 levy standards as a quasi-natural experiment, placing the provinces shown in Table 1 into the treatment group by the date on which they adjusted their SO_2 discharge fees. This study used the DID method to evaluate the impact of improvements in SO_2 levy standards on regional GTFP.

Table 1. The provinces that adjusted Levy Standard of SO_2 Discharge Fee from 2007 to 2014.

Province	Adjusted Date	Pre-Adjusted Price	Adjusted Price
Jiangsu	2007.7.1	0.63 RMB/kg	1.26 RMB/kg
Anhui	2008.1.1		1.26 RMB/kg
Shanxi	2008.1.1		1.26 RMB/kg
Hebei	2008.7.1		1.26 RMB/kg
Shandong	2008.7.1		1.26 RMB/kg
Neimenggu	2008.7.10		1.26 RMB/kg
Guangxi	2009.1.1		1.26 RMB/kg
Shanghai	2009.1.1		1.26 RMB/kg
Yunnan	2009.1.1		1.26 RMB/kg
Guangdong	2010.4.1		1.26 RMB/kg
Liaoning	2010.8.1		1.26 RMB/kg
Tianjin	2010.12.20		1.26 RMB/kg
Xinjiang	2012.8.1		1.26 RMB/kg
Heilongjiang	2012.8.1		0.95 RMB/kg
Heilongjiang	2013.8.1		1.26 RMB/kg
Beijing	2014.1.1		10 RMB/kg
Ningxia	2014.3.1		1.26 RMB/kg
Zhejiang	2014.4.1		1.26 RMB/kg

3. Data and Methods

3.1. Green Total Factor Productivity

This study used the DDF and ML productivity index to measure the GTFP of cities, estimating the effect of PSR on the GTFP of cities using the DID method. The purpose of using the DDF is to reduce the pollution emissions (in this study, industrial SO_2 emissions) while meeting the need for output growth [42,43]. The expression is as follows:

$$\vec{D}_0^t\left(y_t, x_t, b_t; g_y, -g_b\right) = sup[\beta : \left(y_t + \beta g_y, b_t - \beta g_b\right) \in p^t\left(x^t\right)], \quad (1)$$

where $g = (g_y, -g_b)$ is a set direction vector; x is an input vector; y is a “desirable” output vector generally referring to economic growth; t represents the year; b is an “undesirable” output (industrial SO_2 emissions), and $P(x)$ is the feasible output set (for both “desirable” output y and “undesirable” output b) for the given input vector x. β represents the maximum possible quantity of “desirable” output increase and “undesirable ” output decrease.

Färe et al. [44], Tu [42], and Wang et al. [43] set the direction vector as $g^t = (y_t, -b_t)$, with the mathematical programming expression to compute the DDF given by:

$$\vec{D}_0^t\left(y_k^t, x_k^t, b_k^t; y_k^t, -b_k^t\right) = max\beta, \quad (2)$$

$$s.t.\begin{cases} \sum\limits_{k=1}^{K} z_k y_{k,m}^t \geq (1+\beta) y_{k,m}^t, m = 1,\ldots,M \\ \sum\limits_{k=1}^{K} z_k b_{k,j}^t = (1-\beta) b_{k,j}^t, j = 1,\ldots,J \\ \sum\limits_{k=1}^{K} z_k x_{k,n}^t \leq x_{k,n}^t, n = 1,\ldots,N \\ z_k \geq 0, k = 1,\ldots,K \end{cases}. \quad (3)$$

The non-parametric linear programming technique is used to compute the DDFs. $\vec{D}_0^t\left(y_k^t, x_k^t, b_k^t; y_k^t, -b_k^t\right)$ is the distance between the specific region and the 'meta' best-practice frontier (the regions with the largest output and the fewest pollution emission under a specific technical structure and factor input) in a certain period. If the value of the DDF is zero, the city's production is technically efficient; otherwise, it is inefficient. We can construct a TFP index on that basis. Chung et al. [45] define the *ML* index of productivity between period *t* and *t* + 1 as:

$$ML_t^{t+1} = \left\{ \frac{\left[1+\vec{D}_0^t\left(x^t, y^t, b^t; g^t\right)\right]}{\left[1+\vec{D}_0^t\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)\right]} \times \frac{\left[1+\vec{D}_0^{t+1}\left(x^t, y^t, b^t; g^t\right)\right]}{\left[1+\vec{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)\right]} \right\}^{\frac{1}{2}} \quad (4)$$

The *ML* index can be decomposed into efficiency change (*EFFCH*) and technological progress (*TECH*).

$$EFFCH_t^{t+1} = \frac{1+\vec{D}_0^t\left(x^t, y^t, b^t; g^t\right)}{1+\vec{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)} \quad (5)$$

$$TECH_t^{t+1} = \left\{ \frac{\left[1+\vec{D}_0^{t+1}\left(x^t, y^t, b^t; g^t\right)\right]}{\left[1+\vec{D}_0^t\left(x^t, y^t, b^t; g^t\right)\right]} \times \frac{\left[1+\vec{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)\right]}{\left[1+\vec{D}_0^t\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)\right]} \right\}^{\frac{1}{2}} \quad (6)$$

If there were no changes to the inputs and outputs for two time periods, then *ML* = 1. If there has been an increase in productivity, then *ML* > 1, while a decrease in productivity means *ML* < 1. *EFFCH* in Equation (5) indicates the change in output caused by a change in production efficiency. *EFFCH* > 1 indicates that efficiency improved from *t* to *t* + 1, otherwise efficiency declined. *TECH* in Equation (6) indicates the change in output due to technological progress. If *TECH* > 1, technical change enabled the production of more good outputs and fewer bad outputs, otherwise the frontier shifted towards fewer good outputs and more bad outputs. Equation (1) needs to solve four directional distance functions, including the current directional distance function $\vec{D}_0^t\left(x^t, y^t, b^t; g^t\right)$, $\vec{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)$; and two mixed directional distance functions $\vec{D}_0^{t+1}\left(x^t, y^t, b^t; g^t\right)$, $\vec{D}_0^t\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)$.

3.2. Econometric Strategy

3.2.1. Benchmark Difference-in-Differences

The DID method was utilized to study the effect of *PSR* on GTFP. This is described by:

$$Y_{it} = \alpha + \beta PSR_{\mathrm{it}} + \delta x_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (7)$$

where the outcome variable Y_{it} measures the growth of GTFP, as calculated using Equation (4), in city *i* and time *t*. PSR_{it} is an indicator variable; if city *i* adjusted its SO_2 levy standard in year T, and $t > \mathrm{T}$ (Since some provinces implemented *PSR* in the middle of the year, this paper stipulated that, if *PSR* began in July of the current year, the implementation of the province's policy was set as the following year), PSR_{it} is 1, otherwise PSR_{it} is 0. β reflects the effect of the SO_2 levy standards reform on GTFP in the treatment group relative to the control group. μ_i is the city fixed effect, γ_t is the time fixed effect, and ε_{it} is a stochastic disturbance term. X_{it} represents other control variables that also affect GTFP. These variables include:

Economic development, as measured by regional GDP per capita (lngdpp) (This study used the logarithm of GDP per capita, and computed the regional GDP per capita, based on constant 2003 prices, the year before which the analysis starts): may have a serious effect on GTFP due to scale effects and pollutant emissions [46,47]. Moreover, according to the Environment Kuznets Curve theory proposed by Grossman and Krueger [48], there is an inverted U-shaped relationship between economic growth and environmental pollution.

The ratio of foreign direct investment to GDP (fdi_gdp): by introducing advanced foreign technologies and management models, foreign direct investment forced China to strengthen its environmental regulations, thereby increasing GTFP [49].

Technology innovation (inno): Technological innovation is the key driving force in economic growth and GTFP. Here, the city innovation index was utilized to measure technology innovation [50,51].

Industrial structure (ind): Enterprises of different sizes and industries consume different amounts of resources in the production process, thus their contributions to regional GTFP also differ. Optimizing industrial structure improves the allocation efficiency of production factors, which affects GTFP by improving technological efficiency [52–54].

Capital–labor ratio (lncap_l): Yuan et al. [55] found that, compared with other industries, the high-tech industry had better energy efficiency. This study uses the logarithm of the ratio of regional fixed-asset investment to employment in order to evaluate the capital–labor ratio [56]. Table 2 presents details on each variable.

Table 2. Main variables and the associated definitions.

Variable Type	Variable	Description	Definition
Dependent variable Total factor productivity	ML	Malmquist-Luenberger index	
INDEPENDENT variables	PSR	Policy Dummy variable	Dummy variable
Control variables	lngdpp	Regional GDP per capita	Taking the logarithm of regional real GDP per capita
	fdi_gdp	Foreign direct investment	Proportion of the GDP that is made up of FDI
	inno	Technology innovation	City innovation index

Table 2. *Cont.*

Variable Type	Variable	Description	Definition
	ind	Industrial structure	Secondary industry output value/regional GDP
	lncap_l	Capital–labor ratio	Fixed-asset investment/payrolls
Other indicators used in evaluating total factor productivity	y	Gross value of industrial output	
	SO_2	Industrial SO_2 emissions	
	capital	Industrial fixed asset investment	
	labor	Employees in industrial units	
	energy	Industrial electricity consumption	

3.2.2. Parallel Trend Assumption and Time Trend Analysis

The parallel trend assumption is the basic premise of DID analysis. Therefore, this study conducted dynamic effect analysis to test whether the benchmark regression met the parallel trend assumption, as well as to identify the time effect of policy. An event study approach was employed to study the dynamic effect of *PSR* on GTFP. The model is described as follows:

$$Y_{\text{it}} = \alpha_0 + \beta_\tau \sum\nolimits_\tau PSR_{i\tau} + \beta_L PSR_{iL} + \beta_R PSR_{iR} + \delta x_{it} + \mu_i + \gamma_t + \varepsilon_{it}. \quad (8)$$

According to Table 1, 2004–2014 was the period during which SO_2 levy standard reform in the provinces occurred. τ, in this model, identifies the time when the reform began. $\tau = 0$ is when a province implemented *PSR*, $\tau = -1$ refers to the year before implementing *PSR*, and $\tau = -2$ is two years before implementing *PSR*. Therefore, $\tau = [-9, 7]$, other variables are the same as the benchmark model. This study followed Greenstone and Hanna [57] and finally unified $\tau = [-5, 6]$ by excluding $\tau = -1$, the year before publishing *PSR*, to serve as a comparison group. The aim is to obtain adequate sample size for parallel trend assumption and time effect analysis. The model also introduces L and R to replace other periods in order to estimate the average annual effect in the rest years.

3.3. Data

Our study acquired a panel dataset covering 232 cities over the 2004 to 2014 period in China. The sample contains more than two-thirds of all the prefectural-level cities in China. Based on statistics from 2004 and 2014, these 232 prefecture-level cities account for 93.7% of China's total GDP and 97.3% of population of all prefectural-level cities in China. Therefore, the selected sample is representative. The data for the previously-mentioned variables were collected from official sources, e.g., the China Urban Statistical Yearbook and China Yearbook for Regional Economy, etc. Table 3 provides some descriptive statistical results for the variables.

Table 3. The statistical description of the main variables.

Variable	Unit	Observations	Mean	Std.Dev	Min	Max
ML	-	2552	1.041	0.095	0.507	1.992
PSR	-	2552	0.251	0.434	0	1
gdpp	10,000 RMB/person	2552	3.579	3.990	0.261	47.49
fdi_gdp	-	2552	0.022	0.022	0	0.153
inno	-	2552	6.148	30.169	0	666.958
ind	%	2552	50.394	10.698	2.660	90.970
cap_l	10,000 RMB/person	2552	17.993	12.051	0.886	88.048
y	100 million RMB	2552	2405.806	3702.5	11.95	33,000
SO_2	10,000 tons	2552	6.584	6.095	0.006	68.316
capital	100 million RMB	2552	723.537	989.301	19.652	8449.582
labor	10,000 people	2552	18.790	24.874	0.780	260.925
energy	10,000 tons of standard coal	2552	70.985	105.448	0.264	990.279

Notes: Table 3 is a statistical description of the standard numerical values (no logarithm) of the main variables in this study.

4. Empirical Results

4.1. Benchmark Regression Results

Table 4 presents the results from Equation (7) utilizing the panel ordinary least squares method. The effect of PSR on GTFP (DEA-based measure) without control variables is shown in column (1), while columns (2)–(6) list the results as the control variables were gradually introduced in order to re-examine the effects. Table 4 shows that the effect of PSR was statistically significant and negative, regardless of the control variables. This indicated that implementing PSR exerted a negative influence on green growth. Furthermore, PSR decreased GTFP statistically significantly, by approximately 1.86% without control variables and nearly 1.58% with all the control variables. Therefore, this research did not support the Porter Hypothesis, which states that enterprises obtain compensation for innovation by improving their technology when environmental regulations become more stringent. The results coincide with the literature that found that promoting pollution levy standards would increase the cost of environmental governance, crowding out enterprise investment and innovation and ultimately hindering productivity improvements [58,59]. Regarding the five control variables, the coefficients for lngdp and fdi_gdp were positive but statistically insignificant. The coefficients for technological innovation, proportion of secondary industry, and capital–labor ratio were statistically significant and positive, which means that GTFP increased as technology improved and industrial structures were optimized. One possible explanation is that the efficiency of production factors allocation improves with technological innovation and better industrial structures.

Table 4. Benchmark regression results.

	(1)	(2)	(3)	(4)	(5)	(6)
PSR	−0.0186 ***	−0.0160 **	−0.0151 **	−0.0150 **	−0.0125 **	−0.0158 **
	(0.0065)	(0.0064)	(0.0065)	(0.0065)	(0.0061)	(0.0062)
lngdpp		0.0633 ***	0.0609 ***	0.0605 ***	0.0398 ***	0.0213
		(0.0139)	(0.0140)	(0.0140)	(0.0147)	(0.0160)
fdi_gdp			0.3349 **	0.3313 **	0.2803 *	0.1763
			(0.1606)	(0.1612)	(0.1584)	(0.1596)
inno				−0.0000	0.0000	0.0001 *
				(0.0001)	(0.0001)	(0.0001)
ind					0.0017 ***	0.0013 **
					(0.0005)	(0.0005)
lncap_l						0.0016 ***
						(0.0004)
Constant	1.0372 ***	1.0286 ***	1.0197 ***	1.0199 ***	0.9428 ***	0.9570 ***
	(0.0058)	(0.0061)	(0.0071)	(0.0072)	(0.0265)	(0.0267)
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
City effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2552	2552	2552	2552	2552	2552
R-squared	0.0450	0.0502	0.0517	0.0514	0.0549	0.0620

Notes: Robust t-statistics in parentheses; *, **, and *** represent 10%, 5%, and 1% significant levels, respectively.

4.2. Parallel Trend Assumption and Time Trend Analysis

This study tested the parallel trend hypothesis and analyzed the time trend. Figure 1 illustrates the results of Equation (8), reflecting the dynamic effect analysis results of how PSR affects GTFP. β was not significant in the previous policy implementation period, indicating that there was no significant difference between the treatment and control groups before the implementation of the policy, satisfying the parallel trend assumption. After the implementation of the policy, PSR had a negative and statistically significant effect on GTFP, with the negative effect fluctuating over time.

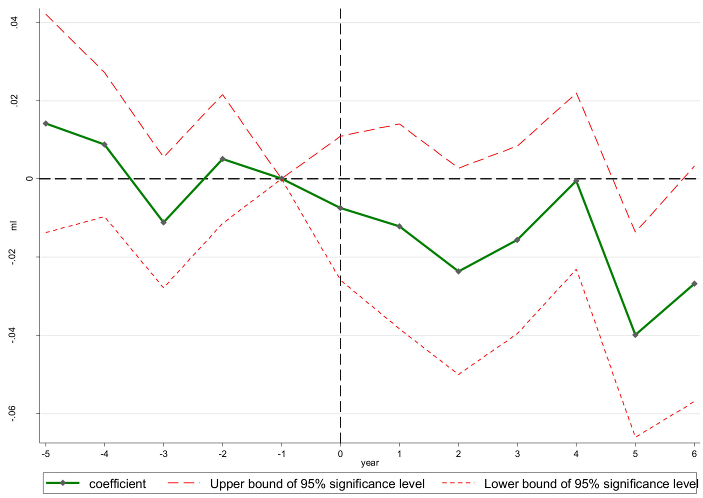

Figure 1. Dynamic effect analysis. Notes: Figure 1 displays the estimated coefficient and its 95% confidence interval in the dynamic model. The year before the policy implementation was used as the benchmark period. Therefore, the estimated coefficient at time −1 is zero. The regression includes year-fixed and city-fixed effects, and the control variables were added to the model.

4.3. Robust Check

Table 4 and Figure 1 both illustrate that, overall, PSR had a statistically significant and negative impact on the growth of regional GTFP. However, in order to ensure the regression results were robust, this study performed four robustness checks (see Table 5).

Table 5. Results of the robustness checks.

	(1)	(2)	(3)	(4)	(5)
PSR	−0.0158 **	−0.0160 ***	−0.0238 ***	−0.0128 **	−0.0161 **
	(0.0062)	(0.0061)	(0.0085)	(0.0065)	(0.0063)
PSR_*preceding*		0.0004			
		(0.0055)			
Constant	0.9570 ***	0.9569 ***	−0.0410	0.9464 ***	0.9576 ***
	(0.0267)	(0.0266)	(0.0349)	(0.0283)	0.0273
Control Variables	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes
City effects	Yes	Yes	Yes	Yes	Yes
Observations	2552	2552	2552	2343	2508
R-squared	0.0620	0.0616	0.0658	0.0671	0.0615

Notes: The dependent variable in columns (1), (2), (4), and (5) was GTFP (as measured by the ML index). Column (1) shows the benchmark regression results. Column (2) shows the counterfactual test with the two-period policy advance. The dependent variable in column (3) was the Luenberger index. Column (4) gives the regression result after eliminating the data from the provinces of Shanxi and Heilongjiang. Column (5) is the regression result after eliminating the data from four municipalities (Beijing, Tianjin, Chongqing, and Shanghai). Robust t-statistics are in parentheses. *, **, and *** represent the 10%, 5%, and 1% levels of significance, respectively.

First, to test the time randomness of PSR, we assumed that the policy began two years earlier and then re-examine PSR's effect on GTFP. We found that the negative effect of PSR on regional GTFP became not statistically significant, and the coefficient was greatly reduced. This regression result is inconsistent with the benchmark regression results, supporting the assumption that the policy implementation times were random.

Second, according to Chambers et al. [60], the Luenberger productivity index involves both a reduction in inputs and an increase in good outputs without choosing a measurement angle, and it is more popular than the Malmquist productivity and ML productivity indexes [59]. Therefore, this study used the Luenberger productivity index to re-examine PSR's effect on GTFP. The results from column (3) suggest that PSR's negative effect on regional total factor productivity was still statistically significant.

Third, the provinces of Shanxi and Heilongjiang stipulated that only enterprises that had not completed the construction of flue gas desulfurization facilities, or whose SO_2 emissions exceeded the standard, should adjust their SO_2 levy standards. Therefore, in the robustness analysis, this study excluded the Heilongjiang and Shanxi provinces from the sample. Column (4) shows that the regression result was consistent with the benchmark regression result, indicating that the regression results were not affected by the data from those two provinces.

Finally, the sample in this study consisted of 232 cities, including Beijing, Shanghai, Tianjin, and Chongqing. Due to the special economic and environmental conditions of these municipalities, we excluded their data to eliminate their city-level impact and further verify the reliability of the estimates. Column 5 lists those results, which reveal that PSR still had a statistically significant inhibitory effect on GTFP, demonstrating that the regression results were robust.

4.4. Mechanism Analysis

Based on the analysis above, PSR led to a statistically significant reduction in the growth of GTFP. A lot of research has examined the factors that affect GTFP. Most research simply divides the ML index into EFFCH and TECH, and then concluded that technological progress is the main source of total factor productivity growth by doing a numerical comparison [43,61]. Following with the existing literature, this section discusses the two direct mechanisms of EFFCH and TECH, aiming to discover whether PSR affects GTFP through EFFCH or TECH. Therefore, we replaced the dependent variable in Equation (7) with EFFCH and TECH to analyze whether PSR affects EFFCH and TECH, with the regression results shown in Table 6; Table 7.

Table 6. The impact of SO_2 levy standards reform on efficiency change.

	(1)	(2)	(3)	(4)	(5)	(6)
	EFFCH	**EFFCH**	**EFFCH**	**EFFCH**	**EFFCH**	**EFFCH**
PSR	−0.0108 *	−0.0092	−0.0083	−0.0088	−0.0068	−0.0087
	(0.0060)	(0.0060)	(0.0060)	(0.0060)	(0.0058)	(0.0059)
lngdpp		0.0386 **	0.0361 **	0.0387 **	0.0226	0.0124
		(0.0151)	(0.0152)	(0.0153)	(0.0165)	(0.0175)
fdi_gdp			0.3497 **	0.3724 **	0.3328 **	0.2754 *
			(0.1574)	(0.1588)	(0.1558)	(0.1600)
inno				0.0001 ***	0.0002 ***	0.0002 ***
				(0.0000)	(0.0000)	(0.0000)
ind					0.0013 ***	0.0011 **
					(0.0004)	(0.0005)
lncap_l						0.0009 **
						(0.0004)
_cons	1.0151 ***	1.0098 ***	1.0006 ***	0.9995 ***	0.9397 ***	0.9475 ***
	(0.0051)	(0.0055)	(0.0069)	(0.0070)	(0.0223)	(0.0228)
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
City effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2552	2552	2552	2552	2552	2552
R-squared	0.0859	0.0875	0.0890	0.0894	0.0912	0.0929

Notes: Robust t-statistics in parentheses; *, **, and *** represent 10%, 5%, and 1% significant levels, respectively.

The results on Tables 6 and 7 show that PSR statistically significantly reduced regional production efficiency and technological progress, without control variables, at the 10% and 5% levels of significance, respectively. However, Table 6 reports that PSR had no significant impact on EFFCH with all control variables were included. Table 7 shows that PSR was statistically significant and negative, whether or not the control variables were included. This indicates that PSR exerted a negative influence on the level of TECH. More specifically, the PSR has significantly decreased TECH by approximately 0.76%, with or without the control variables. Therefore, we concluded that PSR primarily affected GTFP by influencing TECH. One possible explanation is that PSR not only increased enterprise operating costs, but also had a crowding-out effect on the enterprise's productive investment and technological innovation [58]. The increased cost of environmental governance due to stringent environmental regulations crowded out enterprise investment and innovation in other areas, and ultimately hindered productivity improvement.

Table 7. The impact of SO_2 levy standards reform on technological progress.

	(1)	(2)	(3)	(4)	(5)	(6)
	TECH	**TECH**	**TECH**	**TECH**	**TECH**	**TECH**
PSR	−0.0076 **	−0.0067 **	−0.0068 **	−0.0063 **	−0.0060 *	−0.0076 **
	(0.0032)	(0.0032)	(0.0032)	(0.0032)	(0.0032)	(0.0033)
lngdpp		0.0229 ***	0.0233 ***	0.0208 ***	0.0177 **	0.0086
		(0.0069)	(0.0068)	(0.0067)	(0.0072)	(0.0075)
fdi_gdp			−0.0563	−0.0780	−0.0857	−0.1369 *
			(0.0762)	(0.0761)	(0.0754)	(0.0768)
inno				−0.0001 **	−0.0001 **	−0.0001
				(0.0001)	(0.0001)	(0.0001)
ind					0.0003	0.0001
					(0.0002)	(0.0002)
lncap_l						0.0008 ***
						(0.0002)
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
City effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2552	2552	2552	2552	2552	2552
R-squared	0.3095	0.3109	0.3108	0.3125	0.3124	0.3165

Notes: Robust t-statistics in parentheses; *, **, and *** represent 10%, 5%, and 1% significant levels, respectively.

4.5. Heterogeneity Analysis

This section estimates the heterogeneity effects of PSR on GTFP by dividing the samples into different groups. Because China's regional economic development is unbalanced, and because there a great difference in its industrial structures, there are reasons to suspect that the effects of PSR vary between regions. According to the central government's classification [62], the counties in our sample can be divided into the eastern, central, and western regions. To evaluate whether the effects of PSR vary among regions, we divided the sample into the three regions, and then re-estimate the Equation (7). In Table 8, panel A, B, and C display the regression results of the eastern, central and western samples, respectively. The results show that PSR affected the eastern and western regions, but it had no significant effect on the central region. Specifically, PSR statistically significantly inhibits technological advances in the eastern region, which reduces GTFP. However, PSR statistically significantly promoted regional production efficiency in the western region, which increased the GTFP of western China. One possible explanation is that stricter environmental regulations in the eastern region increased the cost of environmental protection, which ultimately leads to a decrease in GTFP. In addition, the "Pollution Haven Hypothesis" suggests that industries will transfer production to regions with weaker environmental pollution regulations [63]. The new industries then promote efficiency and technological innovation in those regions, so the "Pollution Haven Hypothesis" maybe the chief reason that the PSR statistically significantly improved GTFP in the western regions, since that region had relatively lenient environment regulations.

Table 8. Regression results for eastern, central, and western China.

	(1)	(2)	(3)
	ML	**TECH**	**EFFCH**
Panel A Eastern areas			
PSR	−0.0252 ***	−0.0164 **	−0.0112
	(0.0093)	(0.0066)	(0.0100)
Observations	1034	1034	1034
R-squared	0.0897	0.4021	0.1470
Panel B Central areas			
PSR	−0.0096	0.0043	−0.0141
	(0.0142)	(0.0055)	(0.0134)
Observations	902	902	902
R-squared	0.0737	0.3102	0.1001
Panel C Western areas			
PSR	0.0296 **	−0.0024	0.0298 **
	(0.0140)	(0.0059)	(0.0129)
Observations	616	616	616
R-squared	0.0318	0.1871	0.0436
Control Variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes

Notes: Robust t-statistics in parentheses; *, **, and *** represent 10%, 5%, and 1% significant levels, respectively.

According to the Delimitation Scheme of Key Cities for Air Pollution Prevention and Control [64] promulgated in 2002, 113 cities were designated as key environmental protected cities (KEPCs), including municipalities, provincial capitals, open coastal cities, and tourist cities. We then split the sample into KEPCs and non-KEPC and reran (7). Table 9 shows that PSR had no statistically significant effect on GTFP in non-KEPCs, but it statistically significantly reduced GTFP in KEPCs. Column (2) and (3) in Table 9 show that TECH was the main reason why PSR reduced GTFP in KEPCs. This may be because, compared with non-KEPCs, KEPCs are the major cities with greater air pollution control and city planning, and their more stringent environmental regulations may cause enterprises to leave, and regional economic to shrank.

Moreover, environmental regulation may affect small and large cities differently, due to their different levels of efficiency and technology. On the one hand, large-scale cities create an economic agglomeration effect, more efficient resource allocation, and more frequent foreign economic exchange, all of which affect urban productivity, which promotes high-quality development. On the other hand, large-scale cities are vulnerable to crowding effects and aggravated urban problems that lower urban productivity. To decipher the impact of PSR on cities of different sizes, we divided the sample into three segments based on the State Council's city size division standards promulgated in 2014. We categorized cities with populations of less than 1 million as small/medium, large cities as those between 1 and 5 million, and megacities as those larger than 5 million, and re-calculated Equation (7). Table 10 gives the results. The results from panels A and C indicate that PSR had no statistically significant effect on GTFP in small/medium cities or megacities. In panel B, we found that PSR statistically significantly reduced the GTFP of large cities by decreasing TECH and EFFCH, which indicates that the effects of PSR on GTFP vary by city size.

Table 9. Regression results for the key environmental protected city (KEPC) and non-KEPC.

	(1)	(2)	(3)
	ML	**TECH**	**EFFCH**
Panel A KEPCs			
PSR	−0.0185 **	−0.0109 **	−0.0067
	(0.0085)	(0.0050)	(0.0083)
Observations	1177	1177	1177
R-squared	0.0625	0.3778	0.1362
Panel B Non-KEPCs			
PSR	−0.0141	−0.0038	−0.0118
	(0.0088)	(0.0042)	(0.0080)
Observations	1375	1375	1375
R-squared	0.0637	0.2723	0.0649
Control Variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes

Notes: Robust t-statistics in parentheses; *, **, and *** represent 10%, 5%, and 1% significant levels, respectively.

Table 10. Regression results for different city sizes (small/medium, large, and mega).

	(1)	(2)	(3)
	ML	**TECH**	**EFFCH**
Panel A Small/Medium cities (<1 million)			
PSR	0.0312	−0.0043	0.0360
	(0.0369)	(0.0083)	(0.0416)
Observations	77	77	77
R-squared	−0.0317	0.3637	−0.0214
Panel B Large cities (1 < population < 5 million)			
PSR	−0.0217 ***	−0.0096 **	−0.0217 ***
	(0.0080)	(0.0040)	(0.0080)
Observations	1650	1650	1650
R-squared	0.0575	0.2457	0.0619
Panel C Megacities (>5 million)			
PSR	−0.0030	−0.0010	−0.0028
	(0.0100)	(0.0056)	(0.0102)
Observations	825	825	825
R-squared	0.0794	0.4906	0.1904
Control Variables	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes

Notes: Robust t-statistics in parentheses; *, **, and *** represent 10%, 5%, and 1% significant levels, respectively.

5. Discussion

This study used the ML index to calculate GTFP, examined the impact of PSR on the green growth, and thoroughly analyzed the direct impact mechanism. The empirical results showed that PSR has a statistically significant and negative effect on regional GTFP. A series of robustness analyses validated the results, which are contrary to the conclusions of the Porter Hypothesis. In this sample, the growth rates of GTFP and industrial output between 2004 and 2014 were 4.1% and 17.6%, respectively. Therefore, GTFP growth accounts for 23.8% of total industrial output growth in China from 2004 to 2014 (As per Chen [65], the share was defined as the ratio of productivity growth to total industrial output growth). PSR implementation reduced the growth rate of GTFP by 1.58% when including all control variables, so this study concludes that PSR reduced the growth rate of industrial output by 0.37%. PSR in this study may have affected GTFP by promoting efficiency changes and technological progress, but the mechanism analysis proved that PSR only affected GTFP through technological progress. In addition, PSR reduced the technological growth rate by 0.76% when including all control variables. Further analysis found that technological innovation, industry structure, and the proportion of capital-intensive industry could greatly improve regional GTFP. The heterogeneity analysis revealed that PSR had a greater impact on GTFP in eastern region, KEPCs, and large cities and that all affected GTFP through technology. In large cities, PSR affected GTFP by reducing technology and efficiency levels.

This paper, therefore, proposes the following policy suggestions. First, as mentioned above, the effect of PSR on GTFP varies by region. Therefore, different policies should be formulated according to the conditions in each region, such as reasonable environmental tax rates that do not curb local economic development and gradually reduce pollution. Through a suitable environmental policy system, enterprises could gradually improve their environmental performances while achieving high-quality development.

Second, TECH is the main mechanism through which PSR affects GTFP, thus improvements in technological innovation and industrial structure can significantly improve GTFP. Therefore, the government should endeavor to support enterprise innovation and improve enterprise resource allocation and production efficiency. In addition, the government needs to design a better blueprint for guiding regional industrial transformation and promoting regional GTFP.

Finally, in order to achieve a positive policy effect from its environmental protection tax, China needs to improve the measures supporting it, strengthen the scope and intensity of the environmental protection tax, and vigorously construct an environmental legal system. The higher-level government should increase the weight of environmental performance in evaluations of official performance and avoid problems such as "political shielding" and "economics always takes priority" at the expense of the environment.

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Nomenclature

DDF	directional distance functions
DEA	data envelopment analysis
DID	Difference-in-Differences estimation
ML	Malmquist–Luenberger index
GTFP	green total factor productivity

PSR	pollution levy standards reform
KEPCs	key environmental protection cities
x_t	x_t is an input vector in period t
y_t	y_t is a "desirable output" vector in period t
b_t	b is an "undesirable output" in period t
g	g is the vector of directions in which outputs can be scaled
$p_t(x_t)$	$p_t(x_t)$ is the feasible output set for the given input vector x in period t
EFFCH	efficiency change
TECH	technological progress
Y_{it}	Y_{it} is the growth of green total factor productivity measured by ML index
gdpp	regional GDP per capita
fdi_gdp	foreign direct investment
inno	technology innovation
ind	industrial structure
cap_l	capital–labor ratio
y	gross value of industrial output
SO_2	industrial SO_2 emissions
capital	industrial fixed asset investment
labor	employees in industrial units
energy	industrial electricity consumption

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