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Environmental regulation and green productivity: Evidence of the moderating effect of Chinese environmental decentralization

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Abstract: Environmental decentralization (ED), or the allocation of environmental protection affairs and responsibilities among various administrative authorities, affects the effectiveness of environmental regulation in promoting green total factor productivity (GTFP). Based on panel data of 30 Chinese provinces from 2001 to 2015, this paper employs dynamic panel models to test the effects of environmental regulations (environmental protection investment, ENV; pollutant discharge fees, PDF) on GTFP, with or without being influenced by ED. Without the impact of ED, GTFP is significantly inhibited by ENV while significantly promoted by PDF. Considering the impact of ED, with the strengthening of ED, the negative effects of ENV on GTFP is significant; contrarily, the positive effects of PDF on GTFP is significant; improving provincial ED adds negative effects of ENV, while reduces the positive effects of PDF; increasing prefectural ED reduces negative effects of ENV; expanding county-level ED adds the positive effects of PDF. Therefore, to boost GTFP growth, prefectural environmental protection authorities should have more autonomy in ENV, while the county-level should have more autonomy in PDF.

Keywords: Environmental regulation; Green total factor productivity; Dynamic panel model; Environmental decentralization

1. Introduction

In recent decades, sustainable economic growth has gradually replaced traditional economic growth since it contributes to environmental sustainability in economic activities. Green productivity is one of the dominant drivers for sustainable economic growth [1], and reduces pollutant emissions or improves energy efficiency when the desired output is maintained or increased [2]. The early 2000s were China's boom years, nevertheless, the rapid growth model, which relies more on low-cost labor (Labor) and fixed-asset investment growth (Capital) than total factor productivity (TFP) or green total factor productivity (GTFP) (Figure 1), has also caused severe environmental crises, such as air pollution [3]. China is currently facing unparalleled problems to achieve green productivity [4] due to environmental deterioration and a decline in environmental bearing capacity.

Figure 1. Growth in fixed-asset investment, GDP, labor force, GTFP, and TFP from 2001 to 2015 in China

Data source: Authors calculated according to the China Statistical Yearbook and the China Environmental Statistical Yearbook

To boost GTFP, environmental protection policies implemented by local governments play a crucial role in the rise of GTFP [5]. In recent decades, a series of environmental protection policies have focused on environmental protection affairs, such as reducing pollutant emissions and emphasized the environmental responsibility of local governments [6]. According to the 11th Five-Year Plan in 2006, a 10% reduction in the emissions of chemical oxygen demand (COD) and sulfur dioxide (SO₂) was proposed as a binding indicator for each province, and it was suggested to establish the environmental protection target accountability and performance evaluation system for local authorities. In 2011, an 8% reduction in the emissions of ammonia nitrogen and nitrogen oxide was required in the 12th Five-Year Plan in 2011. Furthermore, China's "Environmental Protection Law" published in 2014 stipulates that "local governments shall be in charge of the environmental quality of the region." For better political performance, local governments will implement these environmental protection policies using different environmental regulations, like environmental protection investment, pollutant discharge fees, and environmental taxes, and their impacts on GTFP are worth a closer look. Further, since economic development levels and environmental conditions vary in different parts of China [7], it is of practical significance to explore the correlation between environmental regulation and GTFP in different areas.

A wealth of studies have investigated the effects of environmental regulation on GTFP [8,9] [10,11], among which some took the perspective of fiscal decentralization or environmental decentralization. However, few have taken the influence of environmental decentralization at different administrative levels into account, despite the fact that reasonable environmental decentralization ensures the effectiveness of environmental regulation in promoting GTFP. The long history¹ of environmental decentralization reform has also witnessed its growing importance. Over

¹ In the first stage (1973-1993), the establishment of the National Environmental Protection Leading Group in 1973 marked the beginning of decentralized environmental management. The State Bureau of Environmental Protection, which used to be part of the Ministry of Urban and Rural Environmental Protection as the direct subordinate mechanism of the State Council, began to supervise and manage national environmental protection

the reform process, China's central government has put more emphasis on reforming the environmental management system in recent years and has gradually expanded environmental decentralization by encouraging local governments to participate in environmental protection. As a new contribution to this field, this paper explores the moderating role of environmental decentralization, which includes environmental decentralization at various administrative levels, in the relationship between environmental regulation and GTFP.

Notably, the tasks of local governments include environmental governance and economic growth. On the one hand, with the expansion of environmental decentralization in local authorities, they have more autonomy in allocating environmental protection affairs and responsibilities among different administrative levels. On the other hand, local governments may inadequately execute environmental policies formulated by the central authority when their economic development goals conflict with the central environmental protection targets. Thus, it is necessary to explore the effectiveness of environmental regulation in promoting GTFP growth under the impacts of environmental decentralization. Besides, when it comes to China's environmental protection responsibilities, more in-depth studies are required on how ED at different administrative levels affects the effects of environmental regulation on GTFP.

This paper is structured as follows. Section 2 presents a literature review. Section 3 introduces estimation methods and variables. Section 4 analyses GTFP and provides the empirical results, and Section 5 summarizes conclusions and policy implications.

2. Literature review

Much empirical literature has estimated the impact of environmental regulation on GTFP, but mixed results were reported. Telle and Larsson in 2007 [12] pointed out that environmental regulation positively affected environmental Malmquist productivity. Similarly, Zhang et al. in 2011 [2] observed significantly positive effects of environmental regulation on environmental total factor productivity calculated by the Malmquist-Luenberger (ML) index. Manello in 2017 [13] estimated TFP growth considering environmental pollution and demonstrated that environmental regulation positively impacted the TFP growth in the chemical industry of Italy and Germany. However, the correlation between environmental regulations and GTFP or ETFP is not always positive depending on types of environmental regulations.[6]. Moreover, different environmental regulations have various effects on the green development of different areas in China [14]. Other factors influencing the effectiveness of environmental regulations include regulatory stringency [15], measurement of environmental regulation [16], time-lag [17], fiscal decentralization [10], and so on.

In terms of environmental decentralization, some researchers have argued that decentralization can decrease the efficiency of environmental policies [18] and increase environmental pollution [19] because when local authorities manage environmental affairs, they often choose to loosen environmental regulation for capital inflow, resulting in environmental degradation [20]. Others hold that local governments implement environmental regulations in a more stringent manner as the degree of environmental decentralization increases [21], which helps to reduce regional environmental pollution [22]. In effect, it is suggested that fiscal decentralization as a moderating variable can indirectly affect the effects of environmental regulations on environmental quality or economic growth [10,11]. Similarly, environmental decentralization, when serving as a moderator, can impact the relationship between environmental regulations and GTFP.

affairs in 1988. The second stage (1994-2007) witnessed China's deepening decentralization reform and the incorporation of environmental quality into the performance assessment of local governments. In the third stage (2008-2015), the Ministry of Environmental Protection was founded in 2008. Several environmental protection policies, such as energy conservation and emissions reduction administered by local governments, encouraged local authorities to protect the environment. In the fourth stage (2016-2019), vertical management of environmental protection in the provinces started in 2016.

In short, although the effects of environmental regulation or ED on GTFP are estimated, some limitations remain. First, few researchers have explored the moderating effects of ED on the relationship between environmental regulation and GTFP. Second, fiscal decentralization indicators have been widely used as proxy variables of environmental decentralization, but it covers expenses or revenues of education, technological innovation and so on that are irrelevant with environmental protection. Third, most literature has focused on ED from the central to local authorities, but little research has estimated the ED below the provincial level.

Therefore, this study provides two main contributions. First, from the perspectives of investment and charge, the ENV and PDF are used as proxy variables of different environmental regulation tools to investigate their effects on GTFP. Second, this study creates indexes of ED by using dynamic changes in environmental management staff at different administrative levels to reflect changes in the environmental management system. Then this paper provides the following new insights regarding the moderating effects of environmental decentralization. With the increment of TED, the negative effect of ENV on GTFP is not significant; contrarily, the positive effect of PDF on GTFP is significant; the improvement of PTED adds the negative effect of ENV on GTFP, and reduces the positive effect of PDF on GTFP; the rise of UTED reduces the negative effect of ENV on GTFP, and has no effects on the relationship between PDF and GTFP; the expansion of CTED adds the negative effect of ENV, while the positive effect of PDF on GTFP.

3. Methods and variables

3.1 Estimation methods

Some researchers focused on whether environmental regulations promoted or curbed GTFP and investigated the impacts of various intensities of environmental regulation [23] and different implementation mechanisms [5,6]. This paper uses the two-step difference GMM (DIFF_GMM) model, which controls endogeneity and unobserved time-variable factors [24], to investigate The effects of environmental regulation on GTFP:

$$GTFP_{i,t} = a_0 + b_1 GTFP_{i,t-1} + a_1 ER_{i,t} + \sum_{k=1}^5 s_k Controls_{i,t} + u_i + g_t + e_{i,t} \quad (1)$$

Where $ER_{i,t}$ includes ENV and PDF, where the subscripts represent the province i and year t . The individual and time effects are denoted by u_i and γ_t , respectively. ε_{it} is disturbance term. $GTFP_{i,t-1}$ represents the one-year lag in the variable of GTFP. Control variables (Controls) include five variables: post and tele communications (TELE), industrial structure (STRUCT), technology innovation (TECH), and population density (POPU), economic development level (RGDP), and foreign direct investment (FDI).

Environmental decentralization has been implemented in China for years and requires deeper investigation; thus, the cross-term effects of $ER \times ED$ were included in Equation (2), investigating the moderating effect of ER on GTFP with the influences of ED

$$GTFP_{i,t} = a_0 + b_1 GTFP_{i,t-1} + a_1 ER_{i,t} + a_2 ER_{i,t} \times ED_{i,t} + a_3 ED_{i,t} + \sum_{k=1}^5 s_k Controls_{i,t} + u_i + g_t + e_{i,t} \quad (2)$$

$ED_{i,t}$ includes total environmental decentralization (TED) and its sub-indices, namely, environmental administrative decentralization (AED), environmental supervision decentralization (SED), and environmental monitoring decentralization (MED); the coefficient α_2 presents the effect of the cross-term $ER_{i,t} \times ED_{i,t}$ (ENV×TED, ENV×AED, ENV×SED, or ENV×MED; PDF×TED, PDF×AED, PDF×SED, or PDF×MED).

To estimate the impact of regional environmental regulation on GTFP under different degree of environmental decentralization, TED, PTED, UTED, and CTED are introduced as threshold variables into dynamic threshold panel model, as the following model is constructed:

$$GTFP_{i,t} = a_0 + b_1 GTFP_{i,t-1} + a_1 ER_{i,t} + a_2 ER_{i,t} \times ED_{i,t} \cdot I(q_{i,t} \leq \theta) + a_4 ER_{i,t} \times ED_{i,t} \cdot I(q_{i,t} > \theta) + \sum_{k=1}^5 d_k Control_{i,t} + u_i + g_t + e_{i,t} \quad (3)$$

Where $I(.)$ the function uses the value of 0 or 1; $q_{i,t} \leq \theta$ represents the threshold variable, namely, the total environmental decentralization at different administrative levels. θ represents the threshold value; α_2 and α_4 denote the impact of $ER_{i,t} \times ED_{i,t}$ on $GTFP_{i,t}$ for $q_{i,t} \leq \theta$ and $q_{i,t} > \theta$, respectively. A random grid search is used to obtain the minimum value of the Sargan statistics and optimal threshold θ [25].

3.2 Variables

3.2.1 Green productivity

GTFP is calculated using the Max DEA software. Following Färe et al. (2007) [26] and Oh (2010) [27], GTFP is calculated in 30 provinces in the year 2000-2015 using the Global Malmquist-Luenberger (GML) index as follows:

$$GML_{i,t}^{t,t+1} = \frac{1 + \bar{S}_V^G(x^{i,t}, y^{i,t}, z^{i,t}; g^x, g^y, g^z)}{1 + \bar{S}_V^G(x^{i,t+1}, y^{i,t+1}, z^{i,t+1}; g^x, g^y, g^z)} \quad (4)$$

Where x represents the input variables that include labor force, capital stock, and energy consumption; y is the desired output that is the GDP measured in 2000 prices; z represents the undesirable output, which is the amount of industrial SO₂, COD, and solid waste. g^x, g^y, g^z represent the direction vector of decreasing x , increasing y , and decreasing z , respectively. $\bar{S}_V^G(x^{i,t}, y^{i,t}, z^{i,t}; g^x, g^y, g^z)$ refers to the global distance function.

If $GML_{i,t}^{t,t+1}$ is greater than 1, the GTFP increases from t to $t+1$, and vice versa. Since 2000 is used as the base period (the GTFP in 2000 is 1), and the GTFP in 2000 multiplied by the GML index in 2001 equals to GTFP in 2001, and so on. Additionally, TFP was determined using the Malmquist index without considering the environmental factors and energy consumption.

3.2.2 Environmental regulation

The core explanatory variables are ENV and PDF. ENV is one of the branches of local government fiscal expenditure, and PDF are important resources of fund for pollutant treatment. And they are usually used by governments and public departments to curb environmental deterioration [28]. Based on data availability, Equation (5) is used to measure the level of ENV.

$$ENV_{it} = \frac{ENVI_{it}/P_{it}}{P_{it}/GDP_{it}} \quad (5)$$

Where is $ENVI_{it}$ the total investment in industrial pollution treatment and P_{it} indicates the industrial output of each province. P_{it}/GDP_{it} is used to correct $ENVI_{it}/P_{it}$ to avoid errors resulted from the differences of the industrial structure [29].

Since China imposed the policy of pollutant discharge fees in 1982, these fees are sources of funds for pollution treatment and have exhibited continuously rapid growth in 2001–2015, increasing from 6.218 billion in 2001 to 17.846 billion in 2015. This paper replaced $ENVI_{it}$ in Equation (5) with the PDF in the different provinces.

3.2.3 Environmental decentralization

The calculation methods of environmental decentralization include the proportion of the state's environmental regulations of federal regulations [30], the changes in personnel in the central or local environmental protection system [19], and the use of dummy variables [31]. The difficulties in calculating the decentralization degree occur because the relationships between the different levels

are intricate. With reference to [32], the calculation formula of total environmental decentralization is expressed as follows:

$$TED_{it} = \left[\frac{LEP_{it}/LPOP_{it}}{EP_t/POP_t} \right] \times [1 - GDP_{it}/GDP_t] \quad (6)$$

Where TED_{it} represents environmental decentralization from the central to the local authorities, i.e., the province, municipality, and county. LEP_{it} represents all employees in every province's environmental protection systems; similarly, EP_t represents all staff in the whole country's environmental protection systems. $LPOP_{it}$ represents each province's population and POP_t represents the national population; $[1 - GDP_{it}/GDP_t]$ is an economic reduction factor minimizing the endogenous problem.

The effects of different types of environmental decentralization are influenced by the diversity of environmental management affairs. Equation (5) is used to calculate the three sub-indices by replacing LEP_{it} and EP_t with the all administrative (supervising or monitoring) personnel in local environmental authority and employees in national environmental systems.

China's environmental protection system consists of a block system under the dual management of the Ministry of Environmental Protection and the local authorities. Therefore, personnel mainly distribute in the environmental protection systems at four administrative levels, which include the central, provincial, prefectural, and county levels in China. For instance, the calculation formula of the provincial total environmental decentralization (PTED) is Equation (6). LEP_{it} and EP_t are replaced with all employees of the provincial environmental protection systems in each province and all provincial employees of the environmental protection systems in China. The calculation formulas of the UTED or UTED refer to the method of PTED.

3.2.4 Controls variables

The ratio of the total posts and tele communications to the provincial GDP is used to quantify the level of posts and telecommunications (TELE). Industrial structure (STRUCT) is measured by the proportion of the value-added of the secondary industrial products to the GDP. Technological innovation (TECH) is quantified by using the logarithmic value of the number of patent grants. Economic development level (RGDP) is the logarithmic value of the per capita GDP [5]; Population density (POPU) is the logarithmic value of the population per square kilometer in the administrative area (per 10,000 people/km²). Foreign direct investment (FDI) is the ratio of foreign direct investment to regional GDP.

3.3 Data description

The sample interval is from 2001 to 2015 due to the unavailability of counting employees in prefectural or county-level environmental protection systems after 2015, because China Environmental Statistical Yearbook has only published the total number of environmental protection employees at different departments, such as environmental supervision department and environmental monitoring department of each province, after 2015. The data were obtained from the China Statistical Yearbook and the China Environmental Statistical Yearbook.

Table 1. The statistical description of the variables.

Variables	N	Mean	Std. dev	Min	Median	Max
GTFP	450	1.014	0.161	0.662	1.004	1.893
ENV	450	0.343	0.261	0.014	0.280	1.921

PDF	450	0.357	0.253	0.057	0.293	1.379
TELE	450	0.053	0.022	0.014	0.051	0.119
STRUCT	450	0.394	0.080	0.131	0.411	0.530
TECH	450	8.623	1.633	4.248	8.575	12.510
POPU	450	0.218	0.139	0.006	0.195	0.631
RGDP	450	0.770	0.774	-1.210	0.827	2.369
FDI	450	0.424	0.527	0.047	0.219	5.705
TED	450	0.963	0.352	0.410	0.890	2.264
AED	450	0.987	0.368	0.377	0.905	2.336
SED	450	0.933	0.519	0.125	0.794	2.477
MED	450	0.993	0.361	0.400	0.941	2.520
PTED	450	0.098	0.092	0.020	0.067	0.571
UTED	450	0.238	0.134	0.000	0.209	0.876
CTED	450	0.572	0.301	0.000	0.509	1.728

4. Results and analyses

4.1 Analysis of green productivity

Figure 2 shows the changes in the GTFP and TFP. The average GTFP was higher than the average TFP in all provinces, indicating a production trend featuring fewer pollutant emissions [33]. Specifically, GTFP and TFP had experienced some fluctuations between 2001 and 2015, with TFP ranging from 0.98 to slightly above 1 (2004, 2007), and GTFP from marginally under 1 (2001, 2005, 2014, 2015) to 1.04. A similar trend was observed before 2007; the widest gap occurred in 2008 and then gradually narrowed.

The changes in the TFP in different areas were relatively small, whereas in the GTFP were dramatic. In the eastern part of China, the GTFP was much higher than that of the central and western, steadily and rapidly rising from 2001 to 2010 before slightly dropping in 2011-2014, where these three regions were divided by the method of Hu and Wang (2020)[29]. It is also worth noting that eastern provinces embraced the most obvious difference between GTFP and TFP, representing a sustainable production tendency with less energy consumption and pollution. In the central areas, a virtually same changing pattern was witnessed in TFP and GTFP before 2009, the year when TFP exceeded the GTFP, and since then, the gap had ever grown wider. In western provinces, GTFP had been decreasing and become lower than the TFP after 2003.

Figure 2. Changes in the GTFP and TFP of all provinces ((a) Total), eastern provinces ((b) East), central provinces ((c) Central), and western provinces ((d) West) in China from 2001 to 2015.

4.2 Impacts of environmental regulation on green productivity

Table 2 shows the effects of ENV or PDF on GTFP. The P-values of AR (2) are all larger than 0.1; therefore, the original hypothesis that there is a second-order serial autocorrelation is rejected. The results of Sargan test show that instruments are effective.

The coefficient of ENV is significantly negative in the total sample, which shows environmental protection investment had inhibited the growth of green productivity from 2001 to 2015. The most likely reason for this is that the positive effects of ENV on GTFP need a long term[28]. From the perspective of regional diversity, the coefficient of ENV is positive in the east and central China, while significantly negative in the west. These results mean that environmental protection investment promoted the growth of GTFP in eastern and central provinces from 2001 to 2015, while inhibited the growth of GTFP in western provinces during the period. The coefficient of PDF is significantly positive for all provinces and different regions, which indicates that pollution discharge fees, as resources of funds for pollution treatment, have played a vital role in boosting GTFP growth from 2001 to 2015. Additionally, the coefficients of most control variables are significant, and this indicates that it is necessary to introduce these variables.

Table 2. Impacts of different environmental regulations on GTFP

Variables	Total		East		Central		West	
	ENV	PDF	ENV	PDF	ENV	PDF	ENV	PDF
GTFP _{t,t-1}	0.548*** (0.020)	0.647*** (0.021)	0.634*** (0.025)	0.623*** (0.038)	0.719*** (0.035)	0.628*** (0.053)	0.410*** (0.150)	0.544*** (0.075)
ER	-0.013*** (0.002)	0.053*** (0.004)	0.029 (0.031)	0.087** (0.051)	0.141* (0.049)	0.254*** (0.013)	-0.173* (0.037)	0.040* (0.005)
STRUCT	0.047** (0.047)	0.046*** (0.037)	-0.126 (0.311)	-0.208*** (0.142)	0.093* (0.096)	0.103** (0.090)	0.027 (0.099)	0.146** (0.128)
TECH	0.202*** (0.004)	0.269*** (0.003)	-0.133 (0.033)	-0.007 (0.014)	-0.024 (0.013)	0.188 (0.013)	0.293 (0.015)	0.854*** (0.017)

POPU	0.020** (0.002)	0.023*** (0.002)	-0.056 (0.028)	-0.052** (0.011)	-0.008 (0.010)	0.071 (0.008)	0.091** (0.003)	0.116 (0.007)
TELE	0.062*** (0.041)	0.053*** (0.064)	0.106** (0.432)	0.122*** (0.161)	-0.000 (0.172)	-0.007 (0.164)	0.095 (0.339)	0.075* (0.165)
RGDP	-0.145*** (0.007)	-0.182*** (0.005)	0.251 (0.072)	0.121* (0.022)	-0.134 (0.022)	-0.296** (0.025)	-0.388* (0.028)	-0.856*** (0.028)
FDI	-0.003** (0.000)	0.002 (0.001)	-0.012 (0.004)	-0.005 (0.005)	-0.010 (0.063)	-0.008 (0.060)	0.014 (0.058)	-0.086 (0.072)
AR (1)	-1.381* (0.000)	-1.560* (0.000)	-0.193* (0.000)	-1.980** (0.000)	-1.694* (0.000)	-1.794* (0.000)	-1.732* (0.000)	-1.394 (0.000)
AR (2)	0.822 (0.000)	0.668 (0.000)	0.993 (0.000)	-0.594 (0.000)	0.953 (0.000)	0.784 (0.000)	-0.594 (0.000)	0.877 (0.000)
Sargan test	26.056 [1.000]	27.464 [1.000]	6.347 [1.000]	8.621 [1.000]	5.412 [1.000]	2.769 [1.000]	4.512 [1.000]	4.261 [1.000]
Wald test	9849.55 [0.000]	3473.39 [0.000]	7524.17 [0.000]	2633.18 [0.000]	693.44 [0.000]	1.85e+06 [0.000]	568.94 [0.000]	537.55 [0.000]
N	390	390	143	143	104	104	143	143

Note: standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.001$; the numbers in [] are the P-values of the corresponding test statistics.

4.3 The moderating effect of environmental decentralization

4.3.1 The moderating effect of environmental decentralization between the central and local authorities

Table 3 shows that the coefficients of ENV×AED and ENV×SED are significantly negative. The results indicate that under the influence of supervision environmental decentralization and monitoring environmental decentralization, the environmental protection investment had significantly inhibited GTFP. This can be explained by the fact that expansions of environmental decentralization affect the direction and structure of investment in environmental protection. On the one hand, local authorities usually lower investment in controlling industrial pollution if they have more autonomy in environmental protection investment. On the other hand, under the pressure of economic growth and promotion incentives, local governments tend to invest in environmental projects like urban greening, which has short cycles and rapid returns, to show their political achievements [34].

As for the moderating effects of environmental decentralization on PDF in Table 3, the coefficients of PDF×TED, PDF×AED, PDF×SED, and ENV×MED are significantly positive, indicating that the positive effects of PDF on GTFP are improved with the increasing degree of environmental decentralization. There are two main reasons. For one thing, with the expansion of environmental decentralization, local authorities have more autonomy in developing reasonable benchmarks of pollutant discharge fees, based on environmental situations in their respective administrative areas. For another, pollutant discharge fees are the sources of funds for pollution treatment, and there are few incentives for local officials to loosen the standards of pollutant discharge fees.

Table 3. Estimated results of the moderating effects of different types of environmental decentralization.

Variables	ENV				PDF			
	TED	AED	SED	MED	TED	AED	SED	MED
GTFP _{i,t-1}	0.576***	0.567***	0.612***	0.585***	0.626***	0.628***	0.614***	0.603***

	(0.022)	(0.025)	(0.024)	(0.029)	(0.034)	(0.031)	(0.028)	(0.036)
ER	-0.017***	-0.022***	-0.018***	-0.019***	0.073***	0.068***	0.079***	0.063***
	(0.004)	(0.003)	(0.003)	(0.002)	(0.006)	(0.003)	(0.005)	(0.004)
ER×ED	-0.008	-0.013***	-0.015***	0.003	0.065***	0.028***	0.078***	0.063***
	(0.056)	(0.009)	(0.008)	(0.006)	(0.019)	(0.005)	(0.009)	(0.012)
ED	0.147	0.082***	0.063**	0.025	-0.039*	0.052***	-0.052*	-0.112***
	(0.051)	(0.007)	(0.010)	(0.008)	(0.011)	(0.006)	(0.009)	(0.009)
STRUCT	0.050**	0.067***	0.046	0.041*	0.045**	0.050**	0.054***	0.049***
	(0.045)	(0.052)	(0.062)	(0.046)	(0.044)	(0.045)	(0.041)	(0.038)
TECH	0.215***	0.241***	0.224***	0.226***	0.299***	0.300***	0.308***	0.290***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)
POPU	0.019**	0.028***	0.029***	0.014*	0.014*	0.014**	0.013	0.023***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
TELE	0.055***	0.048***	0.050***	0.056***	0.055***	0.052***	0.054***	0.056***
	(0.048)	(0.055)	(0.058)	(0.056)	(0.061)	(0.073)	(0.064)	(0.059)
RGDP	-0.164***	-0.180***	-0.172***	-0.167***	-0.198***	-0.194***	-0.197***	-0.210***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.006)	(0.007)	(0.008)	(0.006)
FDI	-0.012***	0.020	0.042	-0.013***	-0.003**	0.003*	-0.000	0.002*
	(0.001)	(0.006)	(0.012)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
AR (1)	-1.438*	-1.431*	-1.491*	-1.447*	-1.483*	-1.514*	-1.471*	-1.444*
AR (2)	0.732	0.731	0.782	0.749	0.652	0.611	0.673	0.699
Sargan	22.670	20.390	23.484	24.478	25.647	25.850	25.733	25.971
	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]
Wald test	2540.90	2944.90	2961.58	8286.19	3010.06	1925.07	13109.21	4793.72
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]

Note: standard errors in parentheses; * p<0.10, ** p<0.05, ***p<0.001; the numbers in [] are the P-values of the corresponding test statistics.

4.3.2 The moderating effect of environmental decentralization at different administrative levels in a province

The cross-term effects of environmental regulation and environmental decentralization at various administrative levels (provincial, prefectural, and county-level) on the GTFP are shown in Table 4. With the increment of PTED, ENV and PDF have significantly negative effects on GTFP. Compared with prefectural and county-level environmental management systems, provincial systems are less efficient in environmental governance, such as investing in pollution treatment and charging pollutants, because they have less familiarity with local conditions.

With the expansion of UTED, ENV's promotive effects on GTFP are significantly increased, and the promotive effects of PDF on GTFP are insignificant. Compared with the county-level environmental management system, the prefectural system can allocate a wider range of investments in environmental protection and reduce the repeated investment in some environmental protection projects that can be shared by neighboring counties. Also, under the supervision of provincial and county governments, increasing prefectural environmental decentralization will enhance the effectiveness of investment in industrial pollution control and thus promote regional GTFP.

With the expansion of CTED, ENV's inhibitory effects on GTFP are significantly increased, and PDF's promotive effects on GTFP are significantly increased. Compared with the provincial and prefectural systems, county-level governments are more efficient in providing public goods and

formulating pollution discharge policies owing to the local advantage, thus balancing the relationship between economic growth and environmental protection. For one thing, the strengthening of environmental decentralization will not motivate local environmental protection systems to lower the standards of pollutant discharge fees, the source of pollution treatment funds. For another, compared with provincial and prefectural governments, county-level governments allocate pollutant discharge fees and inspect pollution emissions more efficiently.

Table 4. Estimated results of the moderating effects of total environmental decentralization at the different administrative levels within a province.

Variables	Provincial		Prefectural		County-level	
	ENV	PDF	ENV	PDF	ENV	PDF
GTFP _{i,t-1}	0.594*** (0.034)	0.620*** (0.039)	0.570*** (0.029)	0.608*** (0.043)	0.630*** (0.021)	0.663*** (0.029)
ER	-0.013*** (0.003)	0.048*** (0.008)	-0.018*** (0.003)	0.063*** (0.005)	-0.023*** (0.003)	0.063*** (0.005)
ER×ED	-0.013** (0.037)	-0.041** (0.128)	0.021* (0.064)	0.008 (0.104)	-0.036*** (0.025)	0.073*** (0.022)
ED	-0.081 (0.104)	0.019 (0.255)	-0.025* (0.018)	-0.060*** (0.030)	-0.035* (0.010)	-0.077*** (0.008)
STRUCT	0.027 (0.055)	0.046* (0.050)	0.063*** (0.045)	0.051** (0.045)	0.041* (0.046)	0.067*** (0.036)
TECH	0.165*** (0.004)	0.227*** (0.006)	0.217*** (0.005)	0.252*** (0.003)	0.231*** (0.004)	0.323*** (0.004)
POPU	0.011* (0.001)	0.018** (0.002)	0.019** (0.002)	0.015* (0.002)	0.020*** (0.002)	0.021** (0.002)
TELE	0.056*** (0.058)	0.050*** (0.067)	0.060*** (0.048)	0.055*** (0.062)	0.053*** (0.050)	0.048*** (0.065)
RGDP	-0.126*** (0.007)	-0.144*** (0.010)	-0.167*** (0.008)	-0.179*** (0.005)	-0.180*** (0.008)	-0.226*** (0.008)
FDI	-0.001 (0.001)	0.004** (0.001)	0.012** (0.002)	0.008*** (0.001)	-0.006*** (0.000)	-0.011*** (0.000)
AR (1)	-1.438*	-1.501*	-1.455*	-1.500*	-1.557*	-1.550*
AR (2)	0.658	0.675	0.882	0.613	0.634	0.714
Sargan	24.132 [1.000]	25.544 [1.000]	25.424 [1.000]	26.117 [1.000]	23.556 [1.000]	25.499 [1.000]
Wald test	2607.01 [0.000]	8236.80 [0.000]	1398.71 [0.000]	5262.14 [0.000]	16742.83 [0.000]	5323.31 [0.000]

Note: standard errors in parentheses; * p<0.10, ** p<0.05, ***p<0.001; the numbers in [] are the P-values of the corresponding test statistics.

4.3.3 The moderating effect of environmental decentralization based on the dynamic threshold panel model

As for the effectiveness of ENV in promoting GTFP growth, there are significant threshold impacts of PTED, UTED, or CTED. When PTED and CTED exceed their threshold values, the joint

effects of ENV and PTED or CTED on GTFP range from being significantly negative to non-significantly positive. If UTED is above threshold 0, the joint effects of ENV and UTED on GTFP vary from being non-significantly negative to significantly positive. In terms of the effectiveness of PDF in improving GTFP, there are significant threshold impacts of TED and UTED. If TED exceeds the threshold 0.526, the joint effects of PDF and TED on GTFP are significantly positive. And, there are significant positive effects of pollutant discharge fees on GTFP when the value of UTED is greater than 0.

On the whole, the regression results calculated by the dynamic threshold panel model are consistent with the estimated results in Table 4. The sample distribution shows that at least 95% of the total samples have exceeded the respective thresholds of environmental decentralization at different administrative levels, indicating that environmental protection investment and pollutant discharge fees have significant positive effects on GTFP with the expansion of environmental decentralization.

Table 5. Estimation results of the moderating effects based on the dynamic threshold panel model

P-value		Threshold variables and value	Estimation results	
ENV	PDF		ENV	PDF
[0.838]	[0.026]	TED $\leq$ 0.526	-0.004 (0.106)	-0.040 (0.067)
		TED $>$ 0.526	-0.023 (0.097)	0.087*** (0.021)
[0.079]	[0.208]	PTED $\leq$ 0.026	-0.562* (0.335)	0.309 (0.512)
		PTED $>$ 0.026	0.092 (0.101)	-0.511* (0.279)
[0.002]	[0.066]	UTED $\leq$ 0.000	-0.010 (0.148)	-0.082*** (0.192)
		UTED $>$ 0.000	0.027** (0.069)	0.009 (0.150)
[0.050]	[0.845]	CTED $\leq$ 0.231	-0.111** (0.172)	0.026 (0.055)
		CTED $>$ 0.231	0.045 (0.129)	0.054*** (0.026)

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.001$; the numbers in [] are the P-values of the threshold effect, a threshold effect exists if $P < 0.1$.

4.4 Further analysis of environmental decentralization and its influences

Total environmental decentralization has gradually reduced in China, since the Central Environmental Protection Agency has been more involved in environmental management, and northwest, southwest, northeast, and north China environmental supervision centers hadn't been established until 2002. Thus, changes in environmental decentralization during the year 2001-2015 are worthy of deep analysis, because they influence the effectiveness of environmental regulation in promoting GTFP growth. Figure 3 depicts that changes in degrees of TED, AED, SED, MED, PTED, UTED, and CTED. As shown in Figure 3, while the SED showed a slightly increasing trend, the degree of TED, AED, and MED showed a decreasing trend from 2001 to 2015 in China. To sum up, there were decreases in the negative effects of environmental protection investment on GTFP and the

positive effects of pollutant discharge fees on GTFP with a decline in the total environmental decentralization between the central and local systems.

In terms of environmental decentralization at different administrative levels in a province, CTED was the highest (Figure 3), showing an increasing trend before 2008, followed by a decreasing trend. CTED significantly decreases the negative effects of ENV and the positive effects of PDF. The second-highest figure was UTED. Under the influence of UTED, the positive effects of ENV and the negative effects of PDF rapidly declined after 2006. The lowest was PTED with slight dynamic fluctuations, which slightly impacted the effects of ENV and PDF.

Figure 3. The degrees of total environmental decentralization (ted) and its sub-indices (aed, sed, and med) are shown in (a), and environmental decentralization at different administrative levels (b) during 2001-2015.

Figure 4 presents the calculation results of TED, PTED, UTED, and CTED. Guangxi ranked last in terms of TED, with its degree lower than 0.526, which indicates that the positive effects of PDF on GTFP would increase with an improvement in total environmental decentralization. Chongqing ranked last in terms of UTED, and its degree is 0. With the improvement in total environmental decentralization at the prefectural level, the negative effects of the investment in industrial pollution treatment and the positive effects of PDF on GTFP decreased in Chongqing. In summary, the increasing of TED reduces the negative effects of PDF in the eastern provinces and enhances the positive effects of PDF in the central and western provinces (except Guangxi). The increasing of UTED enhances the positive effects of ENV, reduces the negative effects of PDF in the eastern provinces, and reduce the negative effects of ENV in the central and western provinces (except Chongqing).

Figure 4. Degree of total environmental decentralization at different administrative levels from 2001 to 2015 in China. The black, red, and red lines indicate the degree 0.026, 0.231, and 0.526, respectively.

5. Conclusions and policy implications

The effects of environmental regulations on GTFP are influenced by environmental decentralization because it usually represents the institutional foundation and precondition of environmental protection. Therefore, the appropriate level of environmental decentralization at different administrative levels is of considerable significance to establishing an efficient environmental management system.

Based on panel data of 30 Chinese provinces from 2001 to 2015, this paper compares TFP and GTFP in China. GTFP’s average value was slightly more than 1 and was higher than TFP. This indicates that the process of production tends to be less energy-consuming and polluted in China. The GTFP of the eastern regions was much higher than TFP, and the difference between them had increased over time. However, the opposite occurred in the central and western regions, where TFP was much higher than GTFP. The reason for this is that many industrial enterprises, which are usually accompanied with high pollution and low energy efficiency, have been transferred from eastern coastal areas to central and west regions since 2000.

As for the empirical results of this paper, DIFF_GMM model is employed to estimate the effects of different environmental regulations (environmental protection investment and pollutant discharge fees) on GTFP and to explore the moderating effect of environmental decentralization on this driving mechanism. The following conclusions are obtained.

First, environmental protection investment has negative effects on GTFP, while pollutant discharge fees have significant positive effects on GTFP. This result implies that in China, pollutant discharge fee plays a crucial role in promoting GTFP. In terms of regional heterogeneity in the effects of environmental protection investment, in the east China, the positive effects of environmental protection investment on GTFP are insignificant, while statistically significant in the central China; in the west China, the positive effects of environmental protection investment on GTFP are statistically significant. When it comes to regional heterogeneity in the effects of pollutant discharges fees, in the three regions, pollutant discharges fees significantly promote GTFP growth.

Second, total environmental decentralization has no regulatory effect on environmental protection investment but positive regulatory effects on the pollutant discharge fees. This result indicates that the positive effects of pollutant discharge fees on GTFP increase with the expansion of

total environmental decentralization from central authorities to local systems. In addition, the moderating effects of the sub-indices of the TED on environmental regulation are consistent with the results of TED. Specifically, the joint effects of ENV and AED or SED significantly inhibit GTFP growth; by contrast, AED, SED, and SED significantly increase the positive effects of PDF on GTFP.

Third, as for the regulatory effects of environmental decentralization at different administrative levels within a province i.e., at the provincial, prefectural, and county-level, the results show that the joint effects of prefectural environmental decentralization and environmental protection investment significantly promote GTFP growth. The joint impacts of county-level environmental decentralization and pollutant discharge fees significantly increase GTFP growth. However, the joint effects of provincial environmental decentralization and environmental protection investment or pollutant discharge fees do not promote GTFP growth.

Fourth, there are significant threshold impacts of PTED, UTED, or CTED on the effectiveness of ENV. If PTED is above threshold 0.026, the joint effects of ENV and UTED on GTFP will vary from being non-significantly negative to significantly positive. If UTED is above threshold 0, the joint effects of ENV and UTED on GTFP will vary from being non-significantly negative to significantly positive. If CTED is above threshold 0.231, the joint effects of ENV and CTED on GTFP will vary from being significantly negative to non-significantly positive. In terms of the effectiveness of PDF in improving GTFP, there are significant threshold impacts of TED and UTED. If TED exceeds the threshold 0.526, the joint effects of PDF and TED on GTFP will be significantly positive. And there will be significant positive effects of pollutant discharge fees on GTFP when the value of CTED is greater than 0.231.

Based on the above conclusions, policy recommendations are provided. China's interior regions should seize the opportunity for GTFP growth. Significant regional differences in GTFP indicate that China's central and western provinces should avoid the model of "pollution first, treatment later." Meanwhile, the pollutant discharge fee is a useful tool to promote GTFP growth. And a balanced "environmental regulation mix" system should be established in different regions of China. China's eastern and central provinces should place greater emphasis on environmental protection investment and pollutant discharge fees, whereas western areas should primarily pay attention to pollutant discharge fees.

The environmental decentralization is an institutional foundation and a prerequisite for achieving positive effects of environmental regulations on GTFP. When it comes to heterogeneity of environmental regulations, different environmental decentralization strategies must be formulated to promote GTFP growth. In terms of environmental protection investment, the Central Environmental Protection Agency should be more responsible for designing the structure of investments in environmental governance and supervising the implementation of environmental investment as well as energy expenditure. In this way, the effectiveness of environmental protection investment can be increased in promoting GTFP growth.

As for pollutant discharge fees, local authorities should have more autonomy in designing benchmarks of pollutant discharge fees, verification of pollutant discharge, and monitoring data of environmental quality. One of the main reasons is that local authorities are more familiar with environmental conditions, and they can make the most of information advantages in managing environment. The other is that there are few incentives for local authorities to lower the standard of pollutant discharge fees, in that they are important resources of funding for pollution treatment and regarded as an efficient tool of environmental management. Additionally, environmental protection centers across provinces should establish an environmental management system and reduce interventions by other provincial authorities on environmental management and supervision. And environmental management systems at the county administrative level should be authorized to engage in specific issues, such as collecting pollutant discharge fees and monitoring emission data.

Although this paper makes a quantitative investigation on the relationship among environmental decentralization at different administrative levels, various environmental regulations, and green total factor productivity, one of the limitations of this study is lack of theoretical model derivation that explains the relationship among them. Another limitation is that the province-level

data in this paper does not describe the potential heterogeneity between cities or counties, while the city-level or county-level data can do this and provides a strong explanation due to the large sample size.

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