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Can Market-Oriented Environmental Regulation Tools Improve Green Total Factor Energy Efficiency? Analyzing the Emission Trading System

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Undoubtedly, green total factor energy efficiency plays a pivotal role in achieving energy conservation, emission reduction, and green development goals. China mainly used command-based environmental regulation tools to enhance the green total factor energy efficiency in the early stage. Later, under the new trend of market-oriented reform, the Chinese government introduced market-oriented environmental regulation tools such as carbon rights. However, the effectiveness of market-oriented environmental regulation tools is still unclear. Therefore, this study investigates the impact of market-oriented environmental regulation tools on green total factor energy efficiency by using the data of 265 cities in China. For this purpose, yearly data from 2003 to 2017 are employed using the difference-in-difference method. The empirical results unveil that the emission trading system can significantly improve green all factor energy efficiency. In addition, the heterogeneity analysis shows that the emission trading system is conducive to improving energy efficiency in resource-based cities. Based on the results, this study provides policy enlightenment for market-oriented environmental regulation tools to promote green development according to the local conditions.

Keywords: market-oriented environmental regulation tools, emission trading system, green total factor energy efficiency, difference-in-difference method, energy efficiency

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1 INTRODUCTION

Improving green total factor energy efficiency is an important issue that needs to be solved urgently to realize green development in China's economy from the stage of high-speed growth to the stage of high-quality development. In recent years, China has achieved remarkable results in promoting the reform of energy conservation and consumption reduction as well as green development. The proportion of coal consumption in total energy consumption has declined from 72.8% in 2011 to 56% in 2021. However, coal consumption is still dominant in the primary energy mix and, at the same time, the total carbon dioxide emission has not yet peaked. In addition, the power consumption of China's GDP is about 0.6 kWh/US$, which is far higher than the world average of 0.2 kWh/US$. Under increasing pressure on the ecological resources and environment, improving green all factor energy efficiency is an inevitable choice. The energy sector is mainly liable for environmental degradation (Khan et al., 2021,2022). The role of energy is indispensable to attaining economic development; however, it also adversely affects the environmental quality and is mainly responsible for climate change. Green total factor energy efficiency is one of the easiest and most cost-effective ways to reduce energy usage and combat climatic changes. In the early stage, China mainly focused on command-based environmental regulation tools. Later, China gradually explored market-oriented environmental regulation tools with transaction modes such as emission rights, water rights, and energy rights.

The traditional analysis holds that environmental regulation may reduce energy efficiency in the short term by imposing pollution control costs. In contrast, the "Porter Hypothesis" holds that environmental regulation improves energy efficiency by promoting innovation (Porter and Linde, 1995). The principle of market-oriented environmental regulation tools comes from the "Coase Theorem." The existing literature always uses the emission trading system as a "quasi-experiment" to evaluate whether the environmental regulation policy immediately affects the environmental quality (Lambie, 2010; Calel and Dechezleprê tre, 2016; Zhang et al., 2017; Chen and Chen, 2019). However, they ignore the critical role of energy in promoting energy conservation and emission reduction by market-oriented environmental regulation and have not yet involved the impact of market-oriented environmental regulation on energy conservation and green production efficiency. Based on the specific perspective of green total factor energy efficiency, this study expands the institutional dividend of market-oriented environmental regulation tools for the first time. This research puts green total factor energy efficiency in the impact analysis scope of market-oriented environmental regulation system, which makes up for the lack of comprehensive measurement and analysis. Meanwhile, it also makes up for the lack of empirical tests on market-oriented environmental regulation tools and urban green total factor energy efficiency in the existing literature to a certain extent.

2 LITERATURE REVIEW

2.1 Environmental Regulation and Total Factor Productivity

The relationship between environmental policy and total factor productivity has been controversial in academia. For instance, Gray and Shadbegian (2003) found that mandatory environmental regulation negatively impacts the total factor productivity of the industry. Likewise, Lanoie et al. (2008) found that the additional cost due to increased environmental regulation intensity adversely affects the total factor productivity in the short term. In contrast, Hamamoto (2006) found that environmental regulation leads to an increase in R&D expenditure, which leads to the growth in productivity in Japan's manufacturing sector. Similarly, Testa et al. (2011) confirmed that flexible environmental regulation poses a significant and positive effect on the proportion of R&D investment, increasing the production efficiency. Tang et al., (2015), Rubashkina et al. (2015) and Li and Chen (2016) found that industrial production increased due to the impact of environmental policies. In the production process of enterprises, when environmental regulation improves the environmental performance, it will inevitably affect the activities such as resource redistribution, capital investment, and technological innovation, and ultimately affect the total factor productivity (Hering and Poncet, 2014; Feng and Ye, 2015; Hancevic, 2016; Albrizio et al., 2017). Ren et al. (2019) believed that implementing emission trading in areas with high environmental law rules can effectively improve the total factor productivity. Tang et al. (2020) identified optimal transition timing from command-and-control policies to market-based policies by analyzing the trade-off between the abatement cost and innovation compensation effects of environmental regulations.

2.2 Emission Trading System

The research on the effect of emission rights policy mainly focuses on environmental performance, economic performance, and technological innovation. Betsil and Hoffmann (2011) believed that when designing the total volume control and trading system, the most controversial issue is how to allocate licenses and how to conduct free distribution or auction. On the one hand, the research conclusions of some scholars support the policy effect of emission trading. For instance, Schleich and Betz (2004) found that the emission permit trading system positively impacts the emission reduction of small- and medium-sized enterprises. The enterprises involved in emissions trading have a relatively greater possibility of environmental innovation (Schleich et al., 2009; Anderson and Di Maria, 2010 et al., 2009; Lin and Sun, 2016; Lu et al., 2020). On the other hand, some scholars believe that the effect of emission rights policy is limited. Borghesi et al. (2015) found that implementing the European emissions trading system (EU-ETS) has limited policy effect due to loose quota issuance. Li and Wen (2016) believed that the role of the market mechanism makes the emission reduction effect of emission trading in pilot areas significant. Stein (2019), Cheng et al., (2015) and Zhou et al., (2020) believed that emission trading has no significant emission reduction effect in the pilot areas. Still, it is undeniable that there are long-term economic and environmental dividends. Shi and Li (2020) found that the emissions trading system reduces the energy consumption per unit GDP by increasing marketization, the relationship between government and market, developing the degree of factor market, and improving the green total factor energy efficiency by green innovation.

Based on the above literature, we can conclude that the research on the impact of market-oriented environmental regulation tools on green total factor energy efficiency is limited. Therefore, this study focuses on the samples of 265 cities in China to examine the impact of market-oriented environmental regulation tools on green total factor energy efficiency, and thus, expands the current literature by analyzing the heterogeneous effect of market-oriented environmental regulation in different types of cities at different periods. Based on the above considerations, this study selects emission trading representative of market-oriented environmental regulation tools. It takes cities under the pilot provinces of the emission trading system as the research samples to conduct an in-depth analysis. Additionally, a series of robustness tests on the impact

TABLE 1 | Description of variables.

Variable	Symbol	Measurement	Source
Green total factor energy efficiency	Gtfpe	Calculated by the SBM Malmquist Luenberger index method	CESY
Population density	Density	Obtained by dividing the city's population by the administrative area	CUSY
Industrial structure	Structure	Proportion of the added value of the secondary industry in the regional GDP	CUSY
Per capita GDP	pgdp	The city's GDP is divided by the city's total population	CUSY
Total energy consumption	Energy	Obtained by using night light data simulation measurement	NOAA
Sulfur dioxide emission	SO_2	Representative pollutant emission level	CESY
R&D and innovation capability	Innova	Number of invention patents represents the city's R&D and innovation ability	SIPOC

Note. CESY, China Energy Statistics Yearbook; CUSY, China Urban Statistical Yearbook; NOAA, National Oceanic and Atmospheric Administration; SIPOC, State Intellectual Property Office of China.

TABLE 2 | Descriptive statistics of the main variables.

Variable	Observation	Mean	Std.dev	Minimum	Median	Maximum
Gtfpe	3,815	0.963	0.412	0.237	0.891	6.217
SO_2	4,106	5.587	5.725	0.001	4.126	68.303
Smoke	4,106	3.198	11.682	0.003	1.825	511.372
Effluents	4,106	0.711	0.916	0.001	0.0.453	9.061
lndensity	4,106	5.648	0.809	1.662	5.812	7.513
Structure	4,106	0.421	0.102	0.075	0.424	0.853
lnpgdp	4,106	8.406	0.719	6.013	8.415	13.782
lninnova	4,106	3.691	1.582	0.000	3.506	10.693

mechanisms and path of emission trading system on green total factor energy efficiency are carried out and further investigate the heterogeneous effect of urban resource endowment.

3 RESEARCH DESIGN

3.1 Data Sample

In 2007, China's Ministry of Finance and the Ministry of ecological environment approved 11 provinces to carry out the pilot emission trading system. They set up emission trading centers, marking the formal institutionalization and standardization of China's market-oriented environmental regulation tools. This study considers the panel data of 265 cities from 2003 to 2017 as the research sample. Following the study by Shi and Li (2020), this research sets 2008–2017 as the implementation year of the emission trading system and sets 2003–2007 as the period before the introduction of the system. In the division of the experimental group and the control group, the cities under the jurisdiction of 11 provinces implementing emission trading are the experimental group. The cities under the jurisdiction of the other 20 provinces are used as a control group during the empirical analysis.

3.2 Variable Definition and Data Description

The main explanatory variable is the green total factor energy efficiency (Gtfpe). Following the study by Liu et al. (2017), we used capital, labor, and energy as inputs and GDP as the desired output; the industrial sulfur dioxide (SO_2), the emissions of industrial smoke and dust, and industrial wastewater (effluents) are regarded as undesirable outputs. The SBM Malmquist Luenberger index method is used to calculate each city's green total energy efficiency. **Table 1** shows the variable measurement, symbol, and data sources of the study variables.

The control variables mainly include population density, industrial structure, per capita gross regional product (pgdp), total energy consumption, sulfur dioxide emission (SO_2), and R&D and innovation capability. The descriptive statistics of the study variables are given in **Table 2**. The mean value of green total factor energy efficiency (Gtfpe) is 0.963, the standard deviation is 0.412, the minimum value is 0.237, the median value is 0.891, and the maximum value is 6.217. This indicates significant differences in the energy efficiency among cities during the study's sample period.

3.3 Identification Strategy and Model Setting

This study uses the difference-in-difference (DID) method to estimate the impact of the emission trading system on green total factor energy efficiency. The DID method is a commonly used method for evaluating policy effects. Referring to the research of Wang and Dong (2019) and Shi and Li (2020), the design model is as follows:

$$\begin{aligned}\mathrm{Gtfpeit} = {} & \alpha_0 + \alpha_1 \mathrm{Experiment}_{it} \times \mathrm{post}_{it} + \beta \mathrm{Control}_{it} + \gamma_t + \theta_i \\ & + \mathrm{Province}_j \times \mathrm{Year}_t + \varepsilon_{it}.\end{aligned} \tag{1}$$

In **Eq. 1**, i, t, and j denote the city, year, and province, respectively. The symbol Gtfpeit is the explained variable indicating the efficiency of green total factor energy, while the experiment is a city grouping variable. The pilot city of the

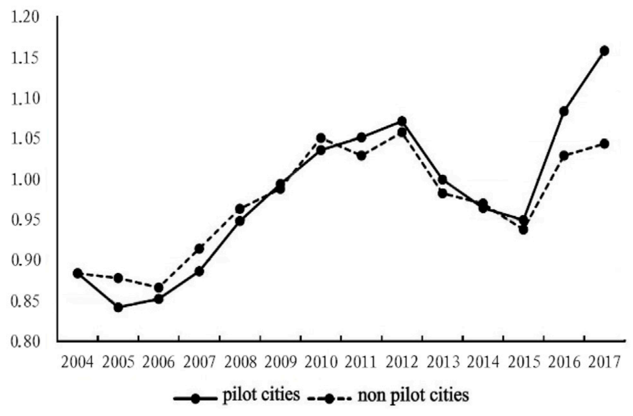

FIGURE 1 | Mean change in the green total factor energy efficiency in pilot and non-pilot cities.

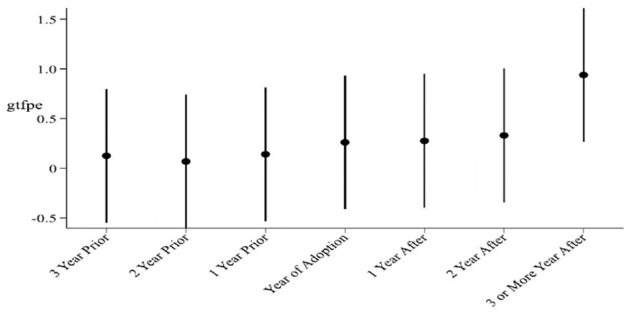

FIGURE 2 | Parallel trend test. Note: The *X*-axis represents the time before and after implementing the emission trading system. The Year of Adoption represents the year in which the emission trading system is implemented. The first 3 years are expressed in Prior, and the last 3 years and above are described in After.

TABLE 3 | Regression results of the DID model: emission trading system and energy efficiency.

	Gtfpe
Experiment × post	0.912** (0.437)
cons	−1.938* (1.132)
N	3,815
Adj-R^2	0.419

*Note: The values in parentheses are standard errors. ***, **, and * represent the significance levels of 1, 5, and 10%, respectively.*

emission trading system in *t* year is denoted as 1, and the non-pilot city is 0. The symbol postit is a time group variable, which is 1 in 2008–2017 and 0 in 2003–2007; Controlit is the control variable group; γt is the time fixed effect; and θi is the urban fixed effect that does not change with time. Moreover, Provincej × Yeart is the individual time effect of provinces, intended to control the influence of unobservable factors of cities over time on the estimation results. The symbol εit represents the random error term.

4 EMPIRICAL RESULTS AND ROBUSTNESS TEST

4.1 Analysis of the Time Trend Chart of Energy Efficiency Change

This study draws on the changing trend of green all factor energy efficiency in pilot cities and non-pilot cities with emission trading systems. **Figure 1** compares the changing trend of the two indicators in the experimental and control groups, and can intuitively reflect the effect of emission trading policies on regional energy efficiency. Before 2010, the green total factor energy efficiency of non-pilot cities was significantly higher than that of pilot cities. However, since 2008, the green all factor energy efficiency of pilot cities increased rapidly and surpassed the non-pilot cities in 2010. In general, the efficiency of pilot cities is stable above the non-pilot cities. So it can be preliminarily considered that the improvement of green total factor energy efficiency in pilot cities relative to the non-pilot cities around 2008 is likely to be induced by the emission trading system.

4.2 Regression Results of the Difference-in-Different Model: Emission Trading System and Energy Efficiency

In order to verify the conjecture obtained from the time trend chart, this study uses the DID method to test it empirically. The sample period is divided by the year of policy implementation, and the system effect is statistically analyzed by comparing the average processing effect before and after policy implementation. The results are shown in **Table 3**. The city, year, and province×year effects are controlled, and the control variables such as population density and industrial structure are introduced. After implementing the emission trading system, compared with the non-pilot cities, from the regression results, the green total factor energy efficiency values of the pilot cities have effectively been improved at a significance level of 5%.

4.3 Precondition for the Application of the Difference-in-Different Model: the Parallel Trend Test

The important premise of using the DID method is that the experimental and control groups should agree with the assumption of a parallel trend. Before the pilot implementation of the emission trading system, the green total factor energy efficiency maintains a relatively stable change trend. Specifically, consider 2008, the pilot year of the emission trading system, as the base year. OLS-DID regression is carried out separately for the explained variables in the first 3 years and the last 3 years and above the base year. The regression results show that the experiment×post coefficient of green total factor energy

TABLE 4 | Emission trading system and energy efficiency: estimation of instrumental variables.

	First stage regression	Second stage regression
—	Experiment × post	Gtfpe
iv × post	0.049*** (0.001)	—
Experiment × post	—	0.136*** (0.040)
cons	0.517 (0.329)	−1.721*** (0.377)
Control	Yes	Yes
Year	No	No
City	Yes	Yes
N	3,815	3,815
Adj-R^2	0.382	0.167
F value of the first stage	28.531	—

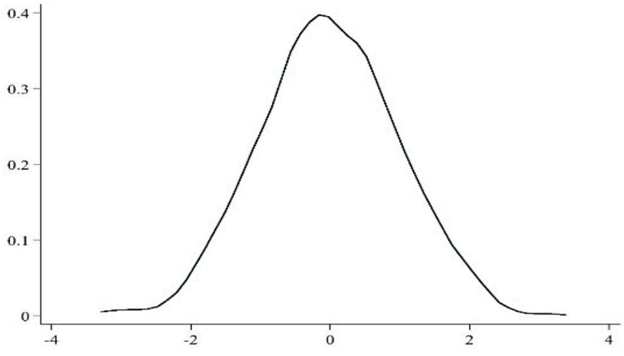

FIGURE 3 | The x-axis represents the t value of the 'experiment × post' coefficient, Y-axis represents its corresponding p-value.

efficiency is not significant in the 3 years before the pilot of the emission trading system. Meanwhile, the regression coefficients are nearly 0, indicating no significant difference between the pilot and non-pilot cities before 2008, which accords with the assumption of a parallel trend. Furthermore, **Figure 2** shows that from the dynamic effect of the parallel trend test, after the third year (after 2011), the green total factor energy efficiency has a significant improvement trend. Meanwhile, it indicates a time lag of about 3 years in the emission trading system based on green total factor energy efficiency.

4.4 Overcoming Endogenous Problems: the Instrumental Variable Method

The selection of pilot cities may be affected by other potential factors, which may interfere with the estimation results of the DID method and affect the accuracy of the results. Therefore, based on the study of Cai et al. (2016), the instrumental variable method is used to overcome the influence of endogenous problems as much as possible. Specifically, based on Shi and Li (2020), the air circulation coefficient is selected as the instrumental variable and included in the pilot cities in the emission trading system. Moreover, meteorological and geographical conditions determine the air circulation coefficient, which can accord with the exogenous hypothesis of instrumental variables.

TABLE 5 | Emission trading system and energy efficiency: PSM-DID model estimation.

	Gtfpe
Experiment × post	1.156** (0.527)
cons	−0.682 (0.816)
Control	Yes
Year	Yes
City	Yes
Province × Year	Yes
N	3,195
Adj-R^2	0.428

The estimation results of the instrumental variables are shown in **Table 4**. The instrumental variable is denoted by iv, which represents the natural logarithm of the annual mean value of the air circulation coefficient of the sample city. In the first stage of regression, the coefficients of the interaction item iv × post of instrumental variables and time variables are significant, and the *F*-values are greater than 10. The results show that the instrumental variables accord with the correlation conditions. In the second stage of regression, the interaction term experiment × post is still significant, indicating that the emission trading system can still significantly improve green total factor energy efficiency after eliminating endogenous problems.

4.5 Robustness Test

4.5.1 Placebo Test

In order to further eliminate the influence of other unknown factors and ensure the accuracy of the research conclusions, a placebo test is used. Specifically, this study conducted 500 samples in all 265 cities and randomly selected 100 cities as the virtual experimental group each time and the other cities as the control group for regression. The kernel density distribution plot of the explained variables in **Figure 3** shows that the absolute value *t* of most sampling estimation coefficients is within 2, and the *p*-value is greater than 0.1, indicating that the emission trading system has no significant effect on these 500 random samples. Therefore, the conclusion of this study can pass the placebo test.

TABLE 6 | Heterogeneity of the impact of the emission trading system on energy efficiency.

	Gtfpe				
	All resource-based city	**Growing resource-based city**	**Mature resource-based city**	**Declining resource-based city**	**Renewable resource-based city**
Experiment × post	0.091*** (0.031)	0.582*** (0.173)	0.071* (0.042)	0.012 (0.067)	0.126*** (0.049)
cons	−1.412*** (0.266)	−0.228 (0.875)	−0.919*** (0.236)	−2.698*** (0.503)	−1.312*** (0.293)
Control	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes
Province × Year	No	No	No	No	No
N	1,539	172	851	315	201
Adj-R^2	0.235	0.463	0.143	0.451	0.537

4.5.2 Propensity Score Matching-Difference-in-Difference Estimation

The sample of this study covers 265 cities across the country. There are significant differences among the sample cities, which may affect the consistency of the estimator and leads to biased results. Therefore, the propensity score matching method (PSM) is used to match the cities of the experimental group and the control group with the control variables as the identification characteristics of the sample points used for regression. The findings in **Table 5** show that the emission trading system significantly improves the green total factor energy efficiency of the pilot cities, indicating that the conclusions obtained in this study are still robust.

4.6 Heterogeneity Analysis: Heterogeneous Impact of Different Types of Resource-Based Cities

The total factor energy efficiency of most resource-based cities is in a state of nonefficiency, and there are significant differences among different types of resource-based cities. China's sustainable development plan for resource-based cities (2013–2020) has established 262 resource-based cities that are divided into four types, growing, mature, declining, and renewable resource-based cities, according to the abundance of resources. **Table 6** reports the results of the heterogeneous impact of the emission trading system on different types of resource-based cities from the perspective of green total factor energy efficiency.

The emission trading system has the most pronounced effect on improving the green total factor energy efficiency in the growing resource-based cities, followed by renewable and mature types. It has no significant impact on the declining types. The possible reason is that in growing resource-based cities, the pressure on environmental protection is slight, and there is a net inflow of labor and capital. As a result, the energy exploitation and total factor energy efficiency are mostly increasing. After experiencing the development stage of high pollution and high energy consumption, renewable resource-based cities have become more aware of cleaner production technology and energy efficiency. The energy utilization and pollution emission of mature resource-based cities are relatively stable. Meanwhile, the technical difference between enterprises is relatively small, resulting in less impact of emission trading system on improving green all factor energy efficiency. With the gradual depletion of energy resources, the production costs of various enterprises increase, and the outflow of labor and capital, resulting in generally low investment in cleaner production technology, and the emission trading market is likely to be stagnant. Therefore, the emission trading system has no significant impact on the green all factor energy efficiency of declining resource-based cities.

5 RESEARCH CONCLUSION AND POLICY IMPLICATIONS

5.1 Research Conclusion

This study considers 265 cities from 2003 to 2017 as a research sample to investigate the impact of market-oriented environmental regulation tools, especially the emission right system, on green total factor energy efficiency using the DID model. The main conclusions are as follows: after a series of robustness tests such as the parallel trend test, instrumental variable method, random sampling simulation test of the experimental group, and PSM method, it is found that the emission trading system significantly improves the green all factor energy efficiency. It is found from heterogeneity analysis that the emission trading system is generally conducive to improving energy efficiency in resource-based cities. The improvement effect of green all factor energy efficiency on the emission trading system is of growing type, renewable type, and mature type from large to small, and the impact on declining type is not significant.

5.2 Policy Implications

From the new perspective of green total factor energy efficiency, this study analyzes in-depth the impact of market-oriented environmental regulation tools, especially on the emission trading system. Additionally, this research discusses the heterogeneity of resource-based cities, providing a targeted empirical basis and policy enlightenment for further improving the emission trading system's energy conservation and consumption reduction as well as the green development effect. Thus, the following policy implications are desirable based on the empirical results.

Market-oriented environmental regulation tools should fully play their role in market-oriented attributes and provide good market trading platforms, intermediary organizations, and legal support for trading subjects, especially in dealing with the synergy between the government and the market in implementing the trading system. The government should not intervene in implementing the trading system but provide necessary trading market supervision, especially paying attention to the design of the cross-regional trading system. At the same time, it should create a good business environment and encourage social capital to participate in transactions. The government should strengthen environmental administrative supervision, increase the monitoring frequency and intensity of pollution sources, and ensure the accurate collection of emission information.

The key link for improving the green total factor energy efficiency is to build an enterprise R&D innovation system. For cities with coal as the main energy consumption structure, we should highlight the R&D investment or technology introduction of clean coal utilization technology by the innovation fund and gradually reduce the proportion of coal consumption in energy consumption. Meanwhile, for cities with advantages in renewable energy development, fiscal, tax, and financial policies supporting the development of emerging industries can be comprehensively applied to provide necessary policy support for the renewable energy power generation industry. The focus should be on the development of high-tech industries and we should strive to eliminate the dependence of economic development on high energy consumption and high pollution industries to improve the green all factor energy efficiency.

The market-oriented environmental regulation tools have a heterogeneous impact on the green total factor energy efficiency. Different pilot cities have significant differences in their economic development, innovation level, energy structure, and other factors, and the implementation effects of environmental regulation tools are significantly different. Therefore, each transaction pilot city cannot adopt the same standard when formulating the policies. It should carry out the transaction pilot construction "according to local conditions" to recognize its particularity to improve the efficiency of green development.

The improvement of green total factor energy efficiency has always been a key area of green transformation and development of the industry. Although the current market-oriented environmental regulation tools had a positive impact, steps to improve the enthusiasm of the main participants in the trading market to a greater extent should be paid more in-depth attention. Including how to build a cross-regional trading market and overcoming the energy rebound effect are important theoretical and practical issues worthy of discussion in the future.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

XW: Conceptualization, data curation, formal analysis, visualization, writing—original draft. ST: writing—original draft and editing. MA: supervision, writing—review, and editing. YB: writing—review, project administration, and editing.

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REFERENCES

Albrizio, S., Kozluk, T., and Zipperer, V. (2017). Environmental Policies and Productivity Growth: Evidence across Industries and Firms. *J. Environ. Econ. Manag.* 81, 209–226. doi:10.1016/j.jeem.2016.06.002

Anderson, B., and Di Maria, C. (2010). Abatement and Allocation in the Pilot Phase of the EU ETS. *Environmental and Resource Economics* 48, 83–103. doi:10.1007/s10640-010-9399-9

Betsill, M., and Hoffmann, M. J. (2011). The Contours of "Cap and Trade": The Evolution of Emissions Trading Systems for Greenhouse Gases. *Rev. Pol. Res.* 28, 83–106. doi:10.1111/j.1541-1338.2010.00480.x

Cai, X., Lu, Y., Wu, M., and Yu, L. (2016). Does Environmental Regulation Drive Away Inbound Foreign Direct Investment? Evidence from a Quasi-Natural Experiment in China. *J. Dev. Econ.* 123, 73–85. doi:10.1016/j.jdeveco.2016.08.003

Calel, R., and Dechezleprêtre, A. (2016). Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market. *Rev. Econ. Stat.* 98, 173–191. doi:10.1162/REST_a_00470

Chen, Z., and Chen, Q. Y. (2019). Energy Efficiency of Chinese Firms: Heterogeneity, Influencing Factors and Policy Implications. *China Ind. Econ.* 12, 78–95. doi:10.19581/j.cnki.ciejournal.2019.12.00510.1007/s12053-018-9687-8

Cheng, B., Dai, H., Wang, P., Zhao, D., and Masui, T. (2015). Impacts of Carbon Trading Scheme on Air Pollutant Emissions in Guangdong Province of China. *Energ. Sustain. Dev.* 27, 174–185. doi:10.1016/j.esd.2015.06.001

Feng, F., and Ye, A. Z. (2015). Does the Rebound Effect Exacerbate the Increasing of China's Total Energy Consumption? *J. Quantitative Tech. Econ.* 32, 104–119. doi:10.13653/j.cnki.jqte.2015.08.007

Gray, W. B., and Shadbegian, R. J. (2003). Plant Vintage, Technology, and Environmental Regulation *Journal of Environmental Economy Management* 46, 384–402. doi:10.1016/S0095-0696(03)00031-7

Hamamoto, M. (2006). Environmental Regulation and the Productivity of Japanese Manufacturing Industries. *Resource and Energy Economics* 28, 299–312. doi:10.1016/j.reseneeco.2005.11.001

Hancevic, P. I. (2016). Environmental Regulation and Productivity: The Case of Electricity Generation under the CAAA-1990. *Energ. Econ.* 60, 131–143. doi:10.1016/j.eneco.2016.09.022

Hering, L., and Poncet, S. (2014). Environmental Policy and Exports: Evidence from Chinese Cities. *J. Environ. Econ. Manag.* 68, 296–318. doi:10.1016/j.jeem.2014.06.005

Khan, I., Hou, F., Zakari, A., Tawiah, V., and Ali, S. A. (2021). Energy Use and Urbanization as Determinants of China's Environmental Quality: Prospects of the Paris Climate Agreement. *J. Environ. Plann. Manag.*, 1–24. doi:10.1080/09640568.2021.1972797

Khan, I., Zakari, A., Zhang, J., Dagar, V., and Singh, S. (2022). A Study of Trilemma Energy Balance, Clean Energy Transitions, and Economic Expansion in the Midst of Environmental Sustainability: New Insights from Three Trilemma Leadership. *Energy* 248, 123619. doi:10.1016/j.energy.2022.123619

Lambie, N. R. (2010). Understanding the Effect of an Emissions Trading Scheme on Electricity Generator Investment and Retirement Behaviour: The Proposed Carbon Pollution Reduction Scheme. *Aust. J. Agric. Resource Econ.* 54, 203–217. doi:10.1111/j.1467-8489.2010.00486.x

Lanoie, P., Patry, M., and Lajeunesse, P. (2008). Environmental Regulation and Productivity: Testing the Porter Hypothesis. *Journal of Productivity Analysis* 30, 121–128. doi:10.1007/S11123-008-0108-4

Li, B., and Chen, C. N. (2016). An Empirical Test of the Impact of Heterogeneous Environmental Regulation on China's Industrial Energy Efficiency. *Stat. Decis.* 03, 129–132. doi:10.13546/j.cnki.tjyjc.2016.03.035

Li, Y. Y., and Wen, Y. F. (2016). A Study on the Efficiency of Emission Trading Policy in China: Empirical Analysis Based on Natural experiment. *Economist* 05, 19–28. doi:10.16158/j.cnki.51-1312/f.2016.05.004

Lin, L., and Sun, W. (2016). Location Choice of FDI Firms and Environmental Regulation Reforms in China. *J. Regul. Econ.* 50, 207–232. doi:10.1007/s11149-016-9303-9

Lu, S., Zhang, W. Z., and Li, J. M. (2020). Influence of Environmental Regulations on Industrial Transformation of Resource-Based Cities in the Yellow River Basin under Resource Endowment. *Bull. Chin. Acad. Sci.* 35, 73–85. doi:10.16418/j.issn.1000-3045.20200107004

Porter, M. E., and Linde, C. v. d. (1995). Toward a New Conception of the Environment-Competitiveness Relationship. *J. Econ. Perspect.* 9, 97–118. doi:10.1257/jep.9.4.97

Ren, S. G., Zheng, J. J., Liu, D. H., and Chen, X. H. (2019). Does Emissions Trading System Improve Firm's Total Factor Productivity: Evidence from Chinese Listed Companies. *China Ind. Econ.* 05, 5–23. doi:10.19581/j.cnki.ciejournal.2019.05.001

Rubashkina, Y., Galeotti, M., and Verdolini, E. (2015). Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis from European Manufacturing Sectors. *Energy Policy* 83, 288–300. doi:10.1016/j.enpol.2015.02.014

Schleich, J., and Betz, R. (2004). EU Emissions Trading and Transaction Costs for Small and Medium Sized Companies. *Intereconomics* 39, 121–123. doi:10.1007/BF02933576

Schleich, J., Rogge, K., and Betz, R. (2009). Incentives for Energy Efficiency in the EU Emissions Trading Scheme. *Energy Efficiency* 2, 37–67. doi:10.1007/s12053-008-9029-3

Shi, D., and Li, S. L. (2020). Emissions Trading System and Energy Use Efficiency: Measurements and Empirical Evidence for Cities at and above the Prefecture Level. *China Ind. Econ.* 09, 5–23. doi:10.19581/j.cnki.ciejournal.2020.09.001

Stein, L. A. (2019). The Legal and Economic Bases for an Emissions Trading Scheme. Monash University. *Journal contribution*. doi:10.26180/5db7fd15ef381

Tang, L., Wu, J., Yu, L., and Bao, Q. (2015). Carbon Emissions Trading Scheme Exploration in China: A Multi-Agent-Based Model. *Energy Policy* 81, 152–169. doi:10.1016/j.enpol.2015.02.032

Tang, M., Li, X., Zhang, Y., Wu, Y., and Wu, B. (2020). From Command-And-Control to Market-Based Environmental Policies: Optimal Transition Timing and China's Heterogeneous Environmental Effectiveness. *Econ. Model.* 90, 1–10. doi:10.1016/j.econmod.2020.04.021

Wang, H., and Dong, Z. Q. (2019). Local-Neighborhood Effect of Green Technology of Environmental Regulation. *China Ind. Econ* 01, 100–118. doi:10.19581/j.cnki.ciejournal.2019.01.006

Zhang, Y.-J., Peng, Y.-L., Ma, C.-Q., and Shen, B. (2017). Can Environmental Innovation Facilitate Carbon Emissions Reduction? Evidence from China. *Energy Policy* 100, 18–28. doi:10.1016/j.enpol.2016.10.005

Zhou, S. J., Luo, X., Liu, Y., and Fan, D. (2020). Research on the Threshold Effect of Environmental Regulation Intensity on Energy Efficiency: Based on PSTR Model. *J. Quantitative Econ.* 37, 9–19. doi:10.16339/j.cnki.hdjjsx.2020.01.002

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