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RESEARCH ARTICLE

The effect of mandatory environmental regulation on green development efficiency: evidence from China

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Abstract
The existing literature finds that mandatory environmental regulation (MER) can significantly reduce environmental pollution. However, much less is known about how the implementation of MER affects green development efficiency (GDE). Based on the Air Pollution Control Action Plan which was enforced in 2013 in China's most developed regions as an exogenous shock, we find that first, MER has a significant negative effect on the improvement of GDE by reducing regional scale efficiency. Second, MER mainly reduces the GDE of cities with stronger regulation intensities and with larger economic volumes. Third, MER also has a negative impact on regional green total factor productivity by changing technical progress. We suggest that when implementing MER, governments should enhance regional and global cooperation, promote green technology, and use comprehensive policy tools to stimulate firms' green innovation.

Keywords Mandatory environmental regulation · Green development efficiency · Super-efficiency SBM model · Difference-in-differences method · Sustainable development

Introduction

Keeping a high level of green development efficiency (GDE) is essential for economic growth (Goodland 1995; Su and Zhang 2020) and for achieving low-carbon economy, which is also the target of Glasgow Climate Pact and Paris Agreement (COP26 2021; Dwivedi et al. 2022). As the world's largest developing country, how to effectively enhance GDE and reduce air pollution is a major challenge for China. Among China's 500 major cities in 2012, less than 1% met the excellent air quality standards. In 2021, there are still 35.7% of China's 338 prefecture-level cities suffering from severe air pollution.[1] Like the actions taken by many developing countries, China mainly reduces air pollution through mandatory environmental regulation (MER) (Liu et al. 2021). In 2013, Chinese central government initiated an MER called Air Pollution Control Action Plan (APCAP), which seeks to reduce air pollution in China's three major city agglomerations: Beijing-Tianjin-Hebei region, Yangtze River Delta, and Pearl River Delta. These three areas account for only 6.44% of China's total land area while possessing more than 44% of the total population. Moreover, these areas contribute approximately 40% of Chinese GDP, which have been the most economically developed regions in China.[2]

The existing studies have shown that APCAP can significantly reduce the emissions of major pollutants, improve ambient air quality, and reduce mortality caused by air pollution (Geng et al. 2019; Feng et al. 2019; Maji et al. 2020). However, less is known about how such policies affect the GDE of cities. In this paper, we apply the implementation

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[1] Bulletin on the state of China's Ecological Environment (2021), Ministry of Ecology and Environment.

[2] Report on Integration of urban agglomerations in China (2019), China Development Research Foundation.

of APCAP as an exogenous shock and empirically test the impact of MER on GDE. Based on the difference-in-differences (DID) analysis, we find that firstly, the implementation of APCAP significantly reduces GDE in Chinese key prevention and control cities. Secondly, the change of scale efficiency (SE) is the main reason that results in the decrease of GDE; thirdly, the higher the target of reducing air pollution in cities with greater economic volume, the larger the negative effects of APCAP on GDE. Fourthly, the implementation of APCAP reduces GTFP by affecting the pure technology efficiency (PTE). The research framework of this paper is shown in Fig. 1.

The contributions of this paper include three aspects: First, we identify the causal relationship between MER and GDE. Second, based on the super-efficiency SBM model with undesired outputs, we reveal the mechanisms behind the relationship between MER and GDE. Third, we further show how the implementation of MER affects GTFP, which is helpful for policymakers to take measures to promote sustainable development and reduce environmental pollution. The remainder of this paper is as follows: part I compares the relevant literature and clarifies the theoretical mechanism, part III introduces methods and data, part IV is empirical results and discussions, and part V summarizes the research conclusions and policy recommendations.

Literature review and theoretical analysis

The impact of environmental regulation on GDE

The existing studies have shown that GDE is an important indicator of regional green development (Yang et al. 2022). However, whether and how environmental regulation can affect GDE is still under debate. While some papers show that environmental regulation will reduce regional GDE (Gray 1987; Xie et al. 2017), others point out that environmental regulation can stimulate firms' technological innovation, which will lead to the increase of GDE (Porter and Van 1995; Peng et al. 2021). Furthermore, some researchers indicate that environmental regulation will reduce firms' innovative inputs in the short term, and lead to a decrease of firm productivity. However, environmental regulation may also promote GDE in the long term (Su and Zhang 2020; Wang 2020). Some studies argue that the impact of environmental regulation on GDE depends on the types of regulation (Ge et al. 2020; Gao et al. 2022).

Compared with these papers, in this study, we try to empirically test the relationship between MER and GDE based on the latest data in the context of China's environmental policies.

The impact of environmental regulation on environmental quality

GDE is closely related to regional environmental quality. Existing studies find that environmental regulation may affect environmental quality by changing the emission of industrial pollution and energy efficiency, which also have a close relationship with GDE (Xiong and Wang 2020; Shahzad et al. 2021; Khan et al.2019). Wang and Li (2021) discover that environmental regulation in China significantly reduce local PM2.5. Neves et al. (2020) shows that environmental regulation in EU countries can reduce the emission of CO_2. However, some studies figure out that environmental regulation does not improve environmental quality. For example, Zhang et al. (2021) point out that there is an inverted U-shaped relationship between environmental regulation and CO_2 emission. Zhang et al. (2019) find that environmental quality in China deteriorates after the implementation of environmental regulations. Environmental regulation may also affect environmental quality through foreign direct investment, technological innovation, green investment, and industrial structure upgrading (Fahad et al. 2022; Shao et al. 2020; Wang et al. 2022; Wang et al. 2021a).

In this study, we try to assess the impact of MER on GDE more comprehensively by introducing GDE as a key dependent variable.

The nonlinear relationship between environmental regulation and GDE

The effects of environmental regulations on GDE reveal the nonlinear relationship between environmental protection and economic development, which is characterized by environmental Kuznets curve (EKC). Since Grossman and Krueger (1993) proposed the idea of EKC, many studies have tested the EKC hypothesis (Isik et al. 2022, 2021; Ongan et al. 2022, 2020; Adebayo 2022; Sharif et al. 2020a; Suki et al. 2020; Chien et al. 2021; Aziz et al. 2020; Isik et al. 2019a; Ahmad et al. 2021a). Research mainly shows that economic growth has a non-linear relationship with environmental quality through technological innovation, renewable energy consumption, increased globalization, and other institutional factors (Adebayo et al. 2022a, b, c; Adebayo and Kirikkaleli 2021; Batool et al. 2019; Godil et al. 2021; Awosusi et al. 2022; Isik et al. 2017; Ali et al. 2021; Amin et al. 2022; Sharif et al. 2019).

In this study, we further analyze the nonlinear relationship between MER and GDE. We argue that the implementation of MER may hinder GDE and thus delay the arrival of the inflection point of the EKC.

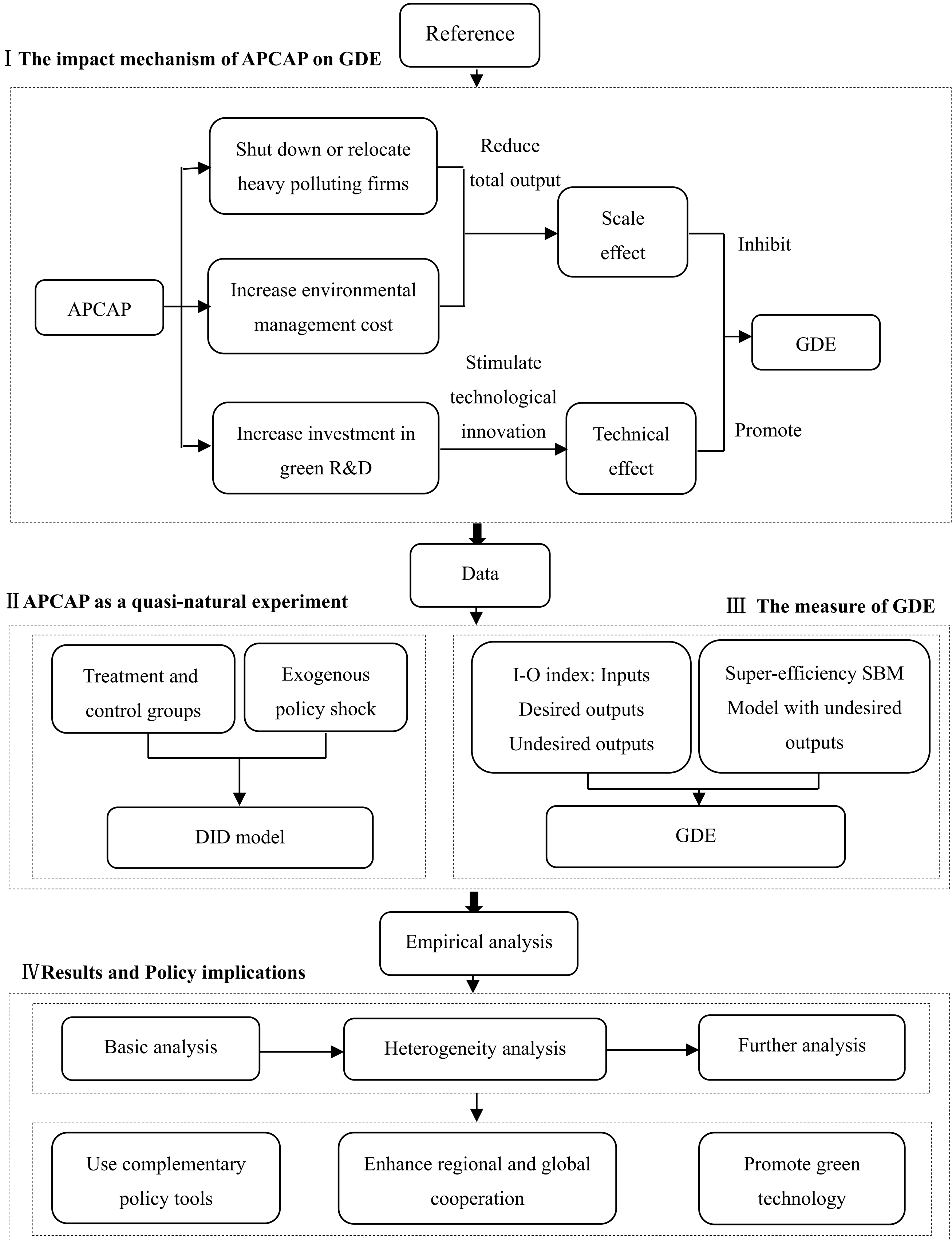

Fig. 1 The research framework

Comments on research literature

Our study is different from the existing research in the following ways. First, unlike existing studies that mainly focus on the impact of environmental regulations on GDP, we pay more attention to the effects of environmental regulation on GDE. Second, while existing studies mainly consider the environmental regulations related to market-oriented policies such as carbon emissions trading systems, we focus on MER, which is seldom considered by previous studies. Finally, unlike existing studies that mainly consider the impact of green regulation on economic efficiency, we further examine the dynamic effects of MER on green efficiency by considering GTFP.

APCAP may impact GDE through both scale effect and technology effect. From the perspective of scale effect, local governments may shut down or relocate highly polluting firms under MER (Wu et al. 2017), leading to the overall decrease of output scale in local areas. Furthermore, because polluting firms may increase investment related to environmental protection such as updating equipment, hiring high-skilled workers, and purchasing green technologies (Wang and Yuan 2018), the overall cost may increase while output will decrease in the short term (Simpson and Bradford 1996). From the perspective of technology effects, because firms affected by MER may increase their investment in green technologies and spending on R&D, in the long term, the GDE may increase. Theoretically, the direction of the influence of MER on GDE is not clear. These mechanisms are presented graphically in the first part of Fig. 1.

Research design and data

Methodology

Identifying the causal relationship between APCAP and GDE is challenging because of the endogenous problems. First, the estimation may be biased by time-varying omitted variables related to regional economic development and air pollution. Second, since the selection of cities is non-random, the unobservable factors associated with the selection criteria may also lead to inaccurate results. DID analysis, which is widely used in studies related to project evaluation and is helpful to evaluate the outcome of policy by comparing the result between the treatment group and the control group (Bertrand et al. 2004), can help to solve the endogenous problem mentioned above. In this paper, we use the implementation of APCAP as a quasi-natural experiment to assess the net effects by comparing the differences between the time periods before and after the implementation of the policy, and by comparing the differences between the treatment group (key prevention and control cities in three areas) and the control group (cities not in these areas) as well.

Specifically, the DID model constructed in this paper is shown in Eq. (1):

$$\text{GDE}_{it} = \alpha + \beta \text{Policy}_{it} \times \text{Time}_{it} + \gamma X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

where GDE_{it} denotes the level of GDE in city i in year t. Policy_{it} is a policy dummy, which equals 1 if city i is in Beijing-Tianjin-Hebei area, Yangtze River Delta, or Pearl River Delta, and otherwise 0. Time_{it} is a time dummy which equals 1 if $t<2013$ and otherwise 0. X_{it} is a vector of control variables at the city level, including GDP per capita, total financial institution loan, foreign investment, and population size. β is the coefficient of our interest, which measures the average changes of the level of GDE in treatment cities compared with control cities after the implementation of the APCAP. μ_i and ν_t are a city and year fixed effect, respectively. ε_{it} is an error term.

The measure of GDE

The core-dependent variable is GDE. We use non-radial, non-angle, and super-efficient SBM method with undesired outputs to measure GDE (Tone 2002). We also decompose the value of GDE into PTE and scale technical efficiency (SE).[3] Specifically, we use capital, labor, and energy as input indicators. The measure of city-level capital is based on the perpetual inventory method: $K_{it} = I_{it} + (1 - \delta)K_{it-1}$, where K_{it} is the value of capital stock in city i in year t. I_{it} is the total capital formation in the year. δ is depreciation rate which is set as 9.6%. The number of employees in a city is denoted as labor input. The value of energy for each city is measured based on the provincial energy consumption weighted by the ratio of city-level GDP to provincial GDP. The desired output is real GDP, and the undesired output is the average value of industrial wastewater, sulfur dioxide, and soot emissions. The input and output indicators are shown in Fig. 2.

In Fig. 3, we visualize the distribution of GDE in each city in 2008 and 2017, respectively.

[3] Comprehensive technical efficiency of urban green development is measured under the condition of constant return to scale (CRS). Pure technical efficiency (PTE) is measured under the condition of variable return to scale (VRS), which refers to the production efficiency affected by technological and managerial factors. Scale efficiency (SE) reflects the difference between the actual scale and the optimal production scale.

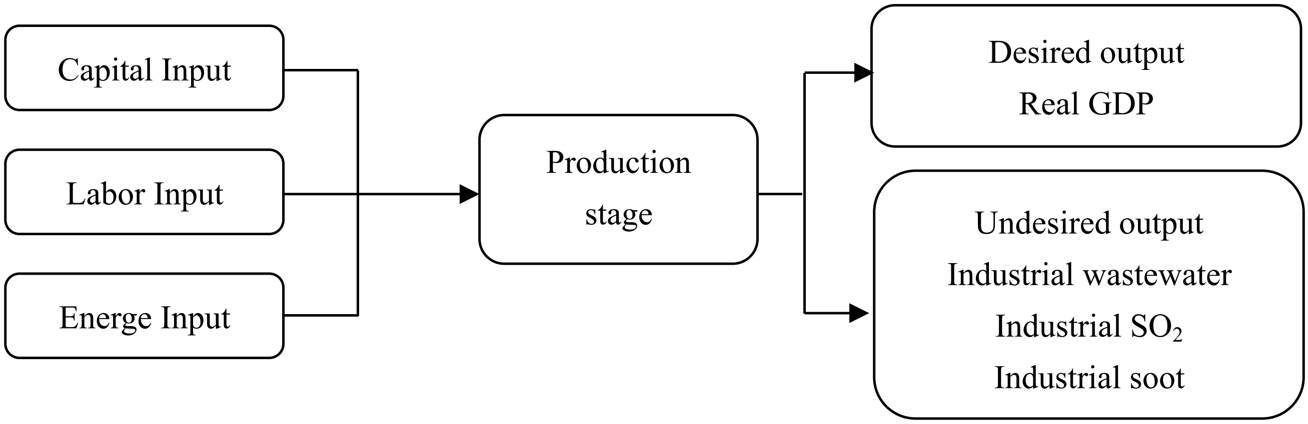

Fig. 2 The input and output indicators for measuring GDE

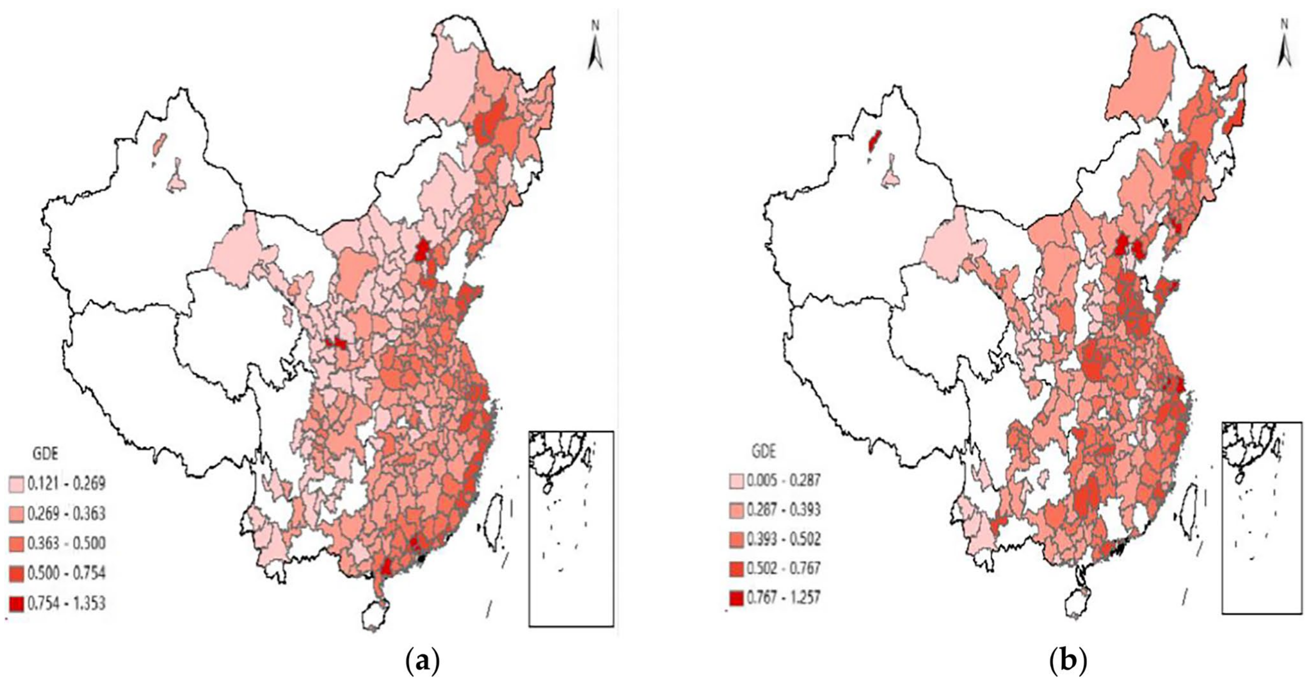

Fig. 3 The distribution of GDE in each city in 2008 and 2017

Data

We construct panel data with 283 prefecture-cities in China from 2008 to 2017. Because China underwent intensive administrative redistricting from 2000 to 2008, and the global financial crisis in 2008 brought a big impact on China's economic growth, in this study, we take 2008 as the starting year. Moreover, because the data of regional capital is not available after 2017, which is essential to measure GDE, we only consider the data before 2017. The data in this study is mainly from China Statistical Yearbook and China Urban Statistical Yearbook from 2009 to 2018. We also collect data from local statistical yearbooks, local government work reports, and official websites of local governments.

Table 1 The descriptive statistics

Variable	Variable meaning	Observation	Mean	S.D
GDE	Green development efficiency	2689	0.387	0.18
PTE	Green development pure technical efficiency	2686	0.548	0.37
SE	Green development scale efficiency	2686	0.737	0.20
GDP	GDP per capita	2689	10.447	0.75
Finance	Total amount of financial institutional loan	2689	16.032	1.20
FDI	Foreign Direct investment	2553	11.906	1.77
Population	Size of Urban Population	2689	5.880	0.69

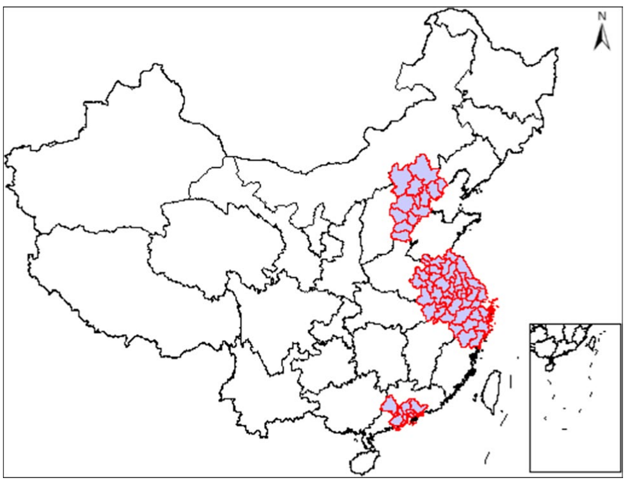

Fig. 4 The distribution of cities in three regions under APCAP

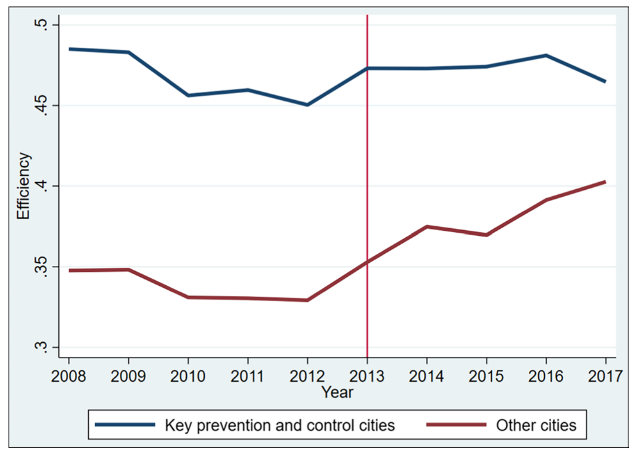

Fig. 5 The average values of GDE of key prevention and control cities and other cities

The results of descriptive statistics of main variables are shown in Table 1.

In our sample, 13 cities are in Beijing-Tianjin-Hebei region, 41 in Yangtze River Delta, and 9 in Pearl River Delta.[4] The distribution of cities in these three areas is shown in Fig. 4.

To examine the relationship between MER and GDE, we first plot the average values of GDE of key prevention and control cities and other cities. The results in Fig. 5 show that the GDE of the two types of cities are parallel before 2013. After the implementation of APCAP in 2013, the GDE of cities in three areas does not continue to increase compared with that of other cities. The results in this graph show that the implementation of APCAP in 2013 has negative effects on regional GDE. Next, we apply DID method to religiously identify the causal relationship between MER and GDE.

Findings and discussions

Basic results

The quantitative results based on model (1) are shown in Table 2. The results in column (1) show that the implementation of APCAP negatively impacts the level of GDE in key prevention and control cities. Specifically, compared with other cities, the level of cities' GDE in three areas decreases by 2.6%, which implies that APCAP hinders the improvement of GDE. These results also echo the studies of Wang and Yuan (2018), Peng et al. (2020), and Ren and Ji (2021), which find the negative relationship between environmental regulation and economic growth. Columns (2) and (3) represent the effects of APCAP on PTE and SE, respectively. The results show that MER significantly reduces the SE of cities in the three areas but does not have effects on PTE (Zou and Zhang 2022). The results based on the SBM model in columns (4)–(6) are much the same, which further indicates the robustness of our basic results.

[4] The cities in Beijing-Tianjin-Hebei region are Beijing, Tianjin, Baoding, Langfang, Tangshan, Shijiazhuang, Handan, Qinhuangdao, Zhangjiakou, Chengde, Cangzhou, Xingtai, and Hengshui in Hebei province.
The cities in Yangtze River Delta are Shanghai and all the cities in Jiangsu, Zhejiang, and Anhui provinces.
The cities in Pearl River Delta are Guangzhou, Shenzhen, Foshan, Dongguan, Zhongshan, Zhuhai, Jiangmen, Zhaoqing, and Huizhou.

Table 2 The effects of MER on GDE

	Super-efficiency SBM model			SBM model		
	(1)	(2)	(3)	(4)	(5)	(6)
	Efficiency	PTE	SE	Efficiency	PTE	SE
Policy × time	−0.026***	−0.002	−0.020**	−0.025***	−0.017	−0.020**
	(0.009)	(0.023)	(0.010)	(0.008)	(0.013)	(0.009)
GDP	−0.098***	−0.196**	−0.046**	−0.092***	−0.099***	−0.051**
	(0.020)	(0.091)	(0.020)	(0.019)	(0.033)	(0.020)
Finance	0.003	−0.100	0.006	0.002	−0.002	0.003
	(0.009)	(0.101)	(0.009)	(0.008)	(0.008)	(0.009)
FDI	0.001	0.016	−0.002	0.001	0.005	−0.002
	(0.002)	(0.011)	(0.003)	(0.002)	(0.004)	(0.003)
Population	−0.175***	−0.290***	−0.000	−0.159***	−0.239***	0.003
	(0.037)	(0.063)	(0.044)	(0.032)	(0.044)	(0.043)
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.911	0.633	0.901	0.919	0.832	0.905
Sample size	2,513	2,510	2,510	2,553	2,553	2,553

Robust standard errors are clustered at the city level. *$p<0.1$; **$p<0.05$; ***$p<0.01$

As for control variables, there is a significantly negative relationship between economic growth and GDE, which implies the contradiction between economic development and environmental protection. The relation between financial development and GDE is not significant, which indicates that the function of financial growth to promote green production is not obvious in China (Zhang et al. 2022). The relationship between FDI and GDE is also insignificant, showing the offsetting results of "pollution halo" (Ritika 2013) and"pollution paradise" (Ayamba et al. 2019). The number of city population has a significantly negative effect on GDE, which shows that population growth in China may increase the consumption of energy and resource, and lead to the decrease of green efficiency (York et al. 2003).

Parallel trend test

The using of DID method requires that the levels of GDE in key prevention and control cities and other cities do not differ systematically before the implementation of APCAP. We take 2012 as the benchmark year and construct nine dummies for each year: 4 years before and 5 years after the implementation of the APCAP. Then we construct interaction terms between these dummies and treatment group dummies, respectively. The coefficients of these interactions are presented visually in Fig. 6 at 95% confidence intervals. The results show that the coefficients of the interactive terms before 2013 are not significantly different from zero, which proves the fulfillment of the parallel hypothesis. After 2013, the estimated coefficients show a negative jump and remain significantly at the 95% level, which further indicates that the GDE of key prevention and control cities is negatively affected by APCAP.

Heterogeneous analysis

According to APCAP, by the end of 2017, the concentration of PM2.5 in Beijing-Tianjin-Hebei region, Yangtze River Delta, and Pearl River Delta must decrease by 25%, 20%, and 15%, respectively. In this section, we further consider the heterogeneous effects of APCAP on GDE. The results in columns (1)–(3) of Table 3 illustrate that the estimated coefficients are only negatively significant when considering the cities in Yangtze River Delta. The potential explanation is that cities in Yangtze River Delta are affected by a higher intensity of environmental regulation compared with that in

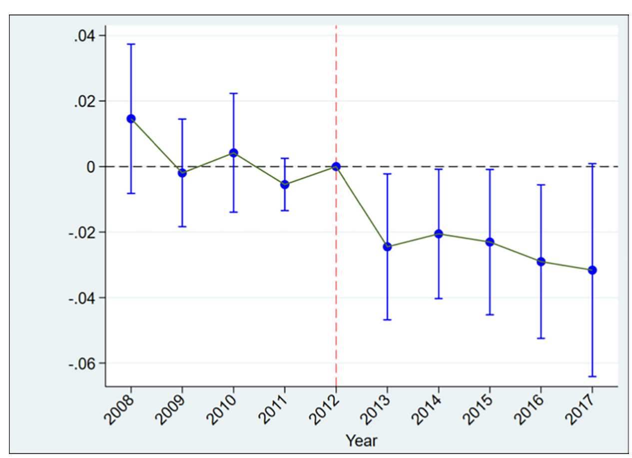

Fig. 6 The parallel trend test

Table 3 The heterogeneous effects of MER on GDE

	Super-efficiency SBM model			SBM model		
	(1)	(2)	(3)	(4)	(5)	(6)
	Beijing-Tianjin-Hebei region 25%	Yangtze River Delta 20%	Pearl River Delta 15%	Beijing-Tianjin-Hebei region 25%	Yangtze River Delta 20%	Pearl River Delta 15%
Policy × time	0.000	− 0.002***	− 0.002	− 0.000	− 0.002***	− 0.001
	(0.001)	(0.001)	(0.002)	(0.001)	(0.000)	(0.001)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.882	0.896	0.896	0.892	0.899	0.907
Sample size	2055	2343	2005	2077	2352	2024

Robust standard errors are clustered at the city level. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table 4 The effects of MER on GTFP

	Super-efficiency SBM-ML index			SBM-ML index		
	(1)	(2)	(3)	(4)	(5)	(6)
	MI	EC	TC	MI	EC	TC
Policy × time	− 0.031***	− 0.011	− 0.016**	− 0.030***	− 0.011	− 0.020***
	(0.010)	(0.012)	(0.007)	(0.010)	(0.010)	(0.007)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.183	0.132	0.446	0.201	0.177	0.537
Sample size	1868	1868	1868	1868	1868	1868

Robust standard errors are clustered at the city level. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Pearl River Delta. Moreover, cities in Yangtze River Delta also have a larger amount of economic volume compared with that in the Beijing-Tianjin-Hebei region. The results in Table 3 imply that APCAP mainly has negative impact on GDE in cities with stronger regulation intensities and with larger economic volumes. The coefficients in columns (4)–(6) of Table 3 are estimated based on SBM model, and the coefficients are much the same.

Further analysis

In this section, we explore the impact of APCAP on GTFP, which is measured by the super-efficient SBM-ML (MI) model. We also decompose MI into technical efficiency change (EC) and technical progress change (TC), respectively. The estimation results in column (1) of Table 4 show that APCAP has significantly negative effects on GTFP. The results in columns (2)–(3) show that APCAP also has negative effects on TC. These findings reflect that although MER may inhibit regional technical improvement, such negative effects are gradually decreasing over time. The results in columns (4)–(6) are based on the SBM-ML model, which is also consistent with the previous estimations.

Conclusions

Improving green efficiency is crucial for sustainable development and has been receiving more and more attention globally in recent years (Zakari et al. 2022; Hassan et al. 2022). At the 2015 UN Sustainable Development Summit, 193 member states signed the 2030 Agenda and established 17 sustainable development goals (SDGs), of which the number of goals related to green development (SDG6, SDG7, SDG13, SDG14, SDG15) accounts for around 30% of the total number of goals (Costanza et al. 2016; Fang 2022). As one of the important measures to improve clean production and sustainable development, Chinese government issued its first comprehensive policy to improve air quality in 2013. In this study, we empirically investigate the causal relationship between APCAP and the level of GDE. We find that first, MER has a significant negative effect on the improvement of GDE by reducing regional scale efficiency. Second, MER mainly reduces the GDE of cities with stronger regulation intensities and with larger economic volumes. Third, MER also has a negative impact on regional GTFP by changing technical progress.

This study has crucial policy implications related to green and sustainable development: Although mandatory environmental policy can control environmental pollution effectively, it may not promote the GDE. Therefore, compared with MER, other policy tools such as levying the environmental tax, offering green subsidies, and constructing emissions trading systems should also be considered supplementary measures by policymakers to enhance the level of GDE. Second, governments should promote local GTFP by stimulating firms to improve green technologies. Third, to promote sustainable development, the cooperation between local governments and across countries ought to be strengthened.

In the future, this study can be expanded from the following aspects. First, it is necessary to consider the spatial spillover effects of the impact of MER on GDE. New methods such as spatial information (SDID-SDM) can be used to identify the spillover effect of environmental regulation on GDE (Wang et al. 2021b; Huang and Chen 2022). Second, the external validity of the findings in this paper needs to be tested by considering other emerging economy countries. Third, the relationship between MER and GDE can be further tested in the context of the current situation when economic uncertainty is raising, and the impacts of the COVID-19 pandemic around the world is still in progress (Isik et al. 2019b; Sharif et al. 2020b; Ahmad et al. 2021b; Irfan et al. 2022).

Author contribution Lei Zhan conceived and designed the study and analyzed the results. Ping Guo provided the data and wrote the paper. Guoqin Pan provided the data, wrote the paper, and analyzed the results. All authors read and approved the final manuscript.

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Data availability The data and materials presented in this study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflicting interests The authors declare no competing interests.

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