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The environmental and economic consequences of environmental centralization: Evidence from China's environmental vertical management reform

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ABSTRACT

Environmental decentralization enhances local autonomy accountability and initiatives. However, some evidence suggests that it might foster a race to the bottom in environmental protection, exacerbating cross-border pollution. Consequently, certain areas in China initiated the vertical management reform of environmental protection agencies (VMR), characterized by centralization, in 1992. The relatively exogenous shock on firms helps to identify the causal effect of VMR on pollution and production. Using the combined data of ASIF and ESR from 1998 to 2013, along with collected policy details at the county-level, we utilize the staggered DID design. Our findings demonstrate that VMR significantly reduces approximately 22.94% of COD emissions from industrial firms. This reduction is achieved through passive approaches such as reducing production, decreasing the entry of firms, and increasing the rate of firms shutting down. Additionally, a proactive approach of increasing the wastewater treatment capacity of individual facilities contributes to this reduction. The impact of VMR is significant in polluting industries, large-scale firms, and firms located at administrative boundaries, mainly driven by local officials with strong promotion incentives. The paper underscores the advantages of environmental centralization, particularly the role of VMR in addressing environmental pollution, especially in the context of transboundary issues. However, due to information asymmetry within centralization, its implementation incurs high economic costs, necessitating more precise and sophisticated regulation.

Abbreviations: VMR, Vertical Management Reform of Environmental Protection Agencies; ASIF, Annual Survey of Industrial Firms; ESR, Environmental Survey and Reporting Database; DID, Difference-in-differences; COD, Chemical Oxygen Demand; PMC, Province-Managing-County; SCEP, Supervision Centers for Environmental Protection; EKC, Environmental Kuznets Curve; EPL, Environmental Protection Law; MEP, Ministry of Environmental Protection; EPB, Environmental Protection Bureaus; GDP, Gross Domestic Product; MEE, Ministry of Ecological Environment; SO_2, Sulfur Dioxide; CPED, Chinese Political Elite Database; MCA, Ministry of Civil Affairs; NH3-N, Ammonia Nitrogen; NECIPS, National Enterprise Credit Information Publicity System; WIPO, World Intellectual Property Organization.

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1. Introduction

Decentralized governance is anticipated to transfer authority, resources, and responsibility from central to sub-national governments, encouraging local economic growth and public welfare provision while enhancing democracy (Faguet, 2014). In the case of China, a country in transition, the decentralization in the economic and financial fields, catalyzed by the tax-sharing reform in 1994 and coupled with the official promotion system, has been considered one of the driving forces behind China's remarkable economic growth (Iimi, 2005). This has led to two primary debates regarding decentralization and centralization. One strand of literature argues that, in comparison with centralization, economic decentralization increases the autonomy of local governments, which is conductive to economic growth (Sanogo, 2019; van der Kamp, Lorentzen, & Mattingly, 2017). In environmental governance, decentralization could enhance political accountability and leverage the advantages of more adequate local information of the local government, so that to better provide public products to meet the public's expectations and to enhance the pertinence and precision of environmental regulations (He, 2015; Hilary, 2014). Besides, through citizens voting with their feet, decentralization may strengthen the accountability of local governments and enhance public participation (Bardhan & Mookherjee, 2005).

Another strand of literature asserts that economic centralization contributes to reducing misallocation of regional resources and enhancing overall productivity (Bo, 2020), while decentralization may lead to deviations in policy implementation or corruption due to inadequate supervision from the central government (Mattingly, 2016). In terms of environmental governance, decentralization may lead local governments to prioritize economic growth at the expense of the environmental concerns, potentially triggering a “race to the bottom” in environmental regulations, cross-border pollution problems, and a loss of efficiency in environmental governance due to the scale-related issues (López & Mitra, 2000; Oates & Schwab, 1988; Wu, Hao, & Ren, 2020). Moreover, although decentralization aids in utilizing democratic mechanisms, in developing countries with imperfect supervision institutions, the mobility of citizens is significantly restricted, limiting citizens' role in overseeing environmental protection under a decentralized system (Bardhan, 2002). In contrast, environmental centralization helps to improve the environmental condition by leveraging economies of scale, strengthening overall supervision and regulation, and addressing spillover effects (Chen, Xu, & Qi, 2022; Zhang, 2017).

Chinese-style decentralization has its particular characteristics, demonstrating in both political centralization and economic decentralization (Xu, 2011; Zhang, 2006). Specifically, within China's unitary political system, it adopts a system where subordinates are appointed and their tenure is assessed by their superiors. This is coupled with economic decentralization stemming from the fiscal-contracting system (Caizheng Baogan). On the one hand, this approach significantly fosters a preference for local economic growth within the local government; however, on the other hand, it leads to discrepancies in optimal decision-making between the central government and local governments. Consequently, this triggers inter-jurisdictional conflicts among local governments, resulting in blind competition for central subsidies, excessive convergence in industrial structure, and environmental issues, etc. Due to the lack of timely and effective supervision, the decentralized “block management” environmental protection system in China exacerbates the conflict between environmental preservation and economic development (Han & Tian, 2022; Jia & Nie, 2017; Zhu, Li, Li, Wu, & Zhou, 2020).

To address the contradiction, China has implemented the vertical management reform of environmental protection agencies (VMR), transitioning from the previous decentralized local management mode known as “block management” to a vertical management termed “line-based, line-block-combined management”.[1] Prior to the VMR, various sectors in China below the provincial level had already adopted vertical management practices, such as in the taxation system (Jun, 2018), the market regulation system (Eggleston, Ling, Qingyue, Lindelow, & Wagstaff, 2008), the mine safety system (Chen, Xu, & Fan, 2015), and the audit system (Cao, Li, Lu, & Xu, 2022). These systems helped resolve specific contradictions between the block and line management systems.

Therefore, this paper specifically focuses on the policy evaluation of the vertical management reform of environmental protection agencies. The research is motivated by the understanding that water resource recycling can alleviate the current water shortage situation (Hami, Al-Hashimi, & Al-Doori, 2007), whereas wastewater, abundant in chemical oxygen demand (COD), poses a serious threat to human health (Chen, Liu, Qi, Yan, & Guo, 2018). Using combined data from the Annual Survey of Industrial Firms (ASIF) and the Environmental Survey and Reporting Database (ESR) spanning from 1998 to 2013, along with collected materials detailing the VMR across counties, we utilize a staggered difference-in-differences (DID) design to showcase that the VMR could effectively reduce the pollutant discharge (COD) of firms by about 22.94%. The policy's impact is notably pronounced in polluting industries, large-scale firms, and those located at the municipal or county administrative boundaries, primarily driven by local officials with strong promotion incentives. Furthermore, our study delves into mechanisms focusing on production reduction, the decrease in the entry of new firms, the firms shutting down rate, and the enhancement of the wastewater treatment capacity of individual facilities. However, it's noteworthy that the reform comes with economic and social costs, leading to employment reduction, reducing investment efficiency, and declining export competitiveness, while there is insufficient evidence to support the notion that the VMR positively impacts green invention patent applications.

The paper contributes to four strands of literature. The first pertains to the extensive literature on decentralization and centralization. Although environmental decentralization grants greater discretion to local governments, it is not conducive to achieving environmental protection goals, particularly exacerbating the problem of cross-border environmental pollution. Conversely, through regulation by the central government, environmental centralization encourages government involvement in environmental enhancement and curbing firms' illegal emissions (Chen et al., 2022; Zhang, 2017). The paper verifies that, within the field of

[1] For more details about block and line management, see Section 3 and appendix A.

environment protection, centralization proves to be an effective method to ameliorate environmental quality.

The second contribution involves the literature on government organizational structure and efficiency. When considering two forms of governmental structure, vertical and flattening structures, there is more information loss under highly vertical management, while highly flattening management, due to a wide range of regulations and a large number of regulated individuals, suffers from inadequate supervision (Patacconi, 2009). In the context of China's province-managing-county (PMC) reform, Bo, Wu, and Zhong (2020) find that a flattening organizational structure detrimentally impacts efficiency. This paper supports the conclusion that in the field of environmental protection, a vertical organizational structure proves more efficient than a flattening structure. This is attributed to the more efficient mechanisms facilitated by the top-down and bottom-up approach, contributing to the policy implementation from the central government.

The third contribution is to provide supplementary discussion on the causes and solutions to China's environmental problems, alongside policy evaluation. Our results align with existing conclusions, that is, China's highly decentralized environmental protection system contributes to the environmental pollution problem to some extent (Han & Tian, 2022; Jia & Nie, 2017; Wang, Mamingi, Laplante, & Dasgupta, 2003). Furthermore, environmental centralization could be deemed an effective remedy and is instrumental in addressing persistent cross-border water pollution issues (Chen et al., 2022).

The fourth contribution pertains to the literature on the impacts of regulations on environmental governance and their economic consequences. We support the notion that environmental regulation serves as an effective tool for addressing environmental problems (Laplante & Rilstone, 1996). However, it comes with certain economic costs, such as contributing to unemployment and economic fluctuations. Our finding offers a micro-level mechanism and foundation for understanding the social welfare impact of centralization.

The most related papers to our research are Chen et al. (2022) and Han and Tian (2022). Chen et al. (2022) examine the impact of the establishment of regional Supervision Centers for Environmental Protection (SCEP) on firm pollution and find that SCEP reduces firms' emissions. Han and Tian (2022) find that the VMR strengthens environmental regulation and that polluting firms reduce sulfur dioxide (SO_2) emissions by reducing the number of coal boilers installed. We support their conclusions while highlight several differences in our research: (1) SCEP focuses on strengthening the supervision mechanism, whereas our research emphasizes the VMR as an institutional and political organizational reform aimed at centralizing authorities. (2) We place greater emphasis on the VMR's role in addressing cross-border water pollution issues at the municipal- and county-levels below the provincial level. (3) Our study involves a more comprehensive discussion of firms' production and innovation behaviors, drawing on a longer observation period from 1998 to 2013. (4) We particularly concentrate on assessing the welfare impact of centralized reforms like the VMR society, particularly its economic costs.

The rest of this paper is organized as follows. Section 2 is literature review. Section 3 introduces the background of vertical management reform. Section 4 describes the research design. Sections 5 and 6 present the empirical results of benchmark model, the heterogeneity, and mechanisms. Section 7 discusses the economic impacts of the VMR. And Section 8 concludes.

2. Literature review

Since the 1860s, the accelerated process of global industrialization led to economic growth, expanded productions, and increased utilization and exploitation of resources (López, 1994). However, this growth also brought about unprecedented environmental challenges, including rapid resource depletion, ecological deterioration, and environmental pollution (Ebenstein et al., 2015), which have drawn worldwide attention (Awaworyi Churchill, Inekwe, Smyth, & Zhang, 2019; Frank, Hironaka, & Schoter, 2000).

These concerns could be classified into three aspects: First, there is always the environmental deterioration in the process of economic development, and it's doubted whether there is the Environmental Kuznets Curve (EKC) (Dasgupta, Laplante, Wang, & Wheeler, 2002; Holtz-Eakin & Selden, 1995). Second, the trade-off between environmental protection and economic efficiency is severe, especially for the transition and developing countries (Roberts & Grimes, 1997; Yahya, Jamil, & Farooq, 2021). Third, there is controversy over the effectiveness and economic costs of environmental regulations, such as mandating technical standards, establishing an emissions-based permit system, or imposing environmental taxes, which help promote environmental protection. For the effectiveness, environmental governance has a large investment scale with a long cycle and a slow return, and due to positive externalities, it can easily lead to the free-riding problem of neighbors. Thus, environmental governance as a public good, its provision is always below the socially optimal level (Fomby & Lin, 2006), which is more serious coupled with the negative externalities of pollution (Wei et al., 2021). As for the economic and social costs, there are two strands of literature. One argues that environmental policies and regulations are not conducive to firm development, such as raising the cost of relocation (Conrad & Wastl, 1995; Copeland & Taylor, 2004), increasing extra environmental costs (Barbera & McConnell, 1990; Jaffe, Trajtenberg, & Henderson, 1993), and reducing firms' profitability (Rassier & Earnhart, 2010). Another strand holds a opposite view that environmental policies can effectively promote technological innovation and thus improve firms' competitiveness (Hamamoto, 2006; Porter & van der Linde, 1995), and in the long term, there may be a U-shape relationship between environmental regulations and firm productivity (Razzaq, Ajaz, Li, Irfan, & Suksatan, 2021).

A critical issue in environmental policy making is which level of governments should bear the specific responsibilities for different environmental regulation (Zhang, Chen, & Guo, 2018). In China, the promulgation of the Environmental Protection Law (EPL) marked the establishment of a four-level environmental supervision and management system in 1989, including the central, provincial, prefectural, and county levels, and stipulated in Article 16: "The local governments at various levels shall be responsible for the environment quality of areas under their jurisdiction and take measures to improve the environment quality",[2] which provides the legal basis for China's environmental decentralization.

Environmental decentralization means local decentralization in economic affairs and hierarchical management in environmental regulation. The institutional construction is the Ministry of Environmental Protection (MEP) as the top governance with about 3000 local environmental protection bureaus (EPB) at all lower levels (specifically including province-level EPB, municipal-level EPB, and county-level EPB),[3] which are jointly responsible for China's environmental regulation activities (Zhang et al., 2018). On the one hand, this type of governance structure fully empowers local governments' autonomy and leverages their information advantages. This enables local governments to effectively balance economic development with the costs of environmental governance (Hilary, 2014). On the other hand, coordination and cooperation between administrative divisions also plays a vital role in environmental problem (Cai, Chen, & Gong, 2016; Sigman, 2002), and this highly decentralized environmental protection system makes it hard for coordination (Han & Tian, 2022; Jia & Nie, 2017; Wang et al., 2003).

The decentralization system also makes the contradiction between economic development and environmental protection more prominent. Since the reform and opening-up, China has impelled local governments to engage in economic development activities with series measures of economic decentralization. The most famous one is "GDP promotion championship", under which higher GDP growth rate is accompanied by higher officials' promotion opportunities (Li & Zhou, 2005). As commented by Blanchard and Shleifer (2001), Chinese officials of local governments bend to promote local economic growth and taxes, which is rare in other developing countries. The decentralized system gives the local government a great discretion, so that local officials prioritize economic development over environmental protection and result in serious environmental pollution (Zhang et al., 2018).

To solve the resource distortion caused by the promotion assessment and incentive system, since the "11th Five-Year Plan",[4] the central government has adjusted the cadre performance assessment standards of officials in the top-level design, to include the environmental performance assessment based on the previous single standard of GDP growth. The one-vote veto system of the environment came into being in 2007, which indicates the local governments have to spare no effort to complete the emission reduction target of mandatory pollutants set by the central government (Zhang, 2021), or will be severely punished in the career promotion. Although the one-vote veto system of the environment has promoted local governments to improve the environment quality (Kahn, Li, & Zhao, 2015), due to its severity, it has greatly curbed the motivation to develop local economy (Tang, Jiang, & Mi, 2021). For example, the government sometimes chooses to shut down firms with large pollution discharge, bringing out unemployment (Yang, Hong, Jung, & Lee, 2015) and production losses (Ali & Puppim de Oliveira, 2018), and sometimes officials even falsify data to pass the assessment (Heberer & Senz, 2011).

Currently, only a handful of papers research on the VMR. Some scholars analyze the motivation, content, and achievements of the VMR from a theoretical perspective (Zhou, 2020) and take the water quality of Hebei Province as a case study (Xu, 2022); In empirical analysis, it is found that the VMR can improve air quality (Du & Wang, 2023) and reduce sulfur dioxide emissions, but there are certain economic costs (Han & Tian, 2022). For a certain specific aspect of VMR, Kong and Liu (2024) find that the centralization of authority in the appointment of local EPB directors during VMR would increase environmental penalties.

To sum up, under China's unique decentralization system and official promotion system, highly decentralized environmental regulation and environmental monitoring may not be conducive to environmental protection (Wu et al., 2020). However, concentrating all powers in the central government will increase its regulatory distance and governance cost and create serious information asymmetry issues (Chen et al., 2022). The choice of centralized or decentralized strategy in environmental governance is an urgent problem to be solved in China. Therefore, it is of practical significance to objectively evaluate the impact of the vertical management reform of China's environmental protection agencies on the emissions and production behaviors of firms and the economic costs generated.

3. China's environmental vertical management reform

The Tiao-Kuai (literally "line and block") system forms the basis of China's political governance.[5] Under this system, China's environmental protection management embodies characteristics of regional segmentation and decentralization (Han & Tian, 2022). Previously, local governments typically employed a "block management" approach, resulting in economic development at the expense of the environment and local government intervention in environmental monitoring, supervision, and law enforcement. Thus, to strengthen the role of local EPBs in environmental protection and clarify the responsibilities of local governments, China initiated the

[2] Article 16, Chapter 3 of the Environmental Protection Law of China (Environmental Protection Law (EPL), 1989). http://www.lawinfochina.com/display.aspx?id=1208&lib=law&SearchKeyword=Environmental%20Protection%252%200Law&SearchCKeyword= (Last consulted 29 Feb 2016).

[3] After 2018, the Ministry of Environmental Protection (MEP) was renamed the Ministry of Ecological Environment (MEE) (Karplus, Zhang, & Zhao, 2021).

[4] From 2006 to 2010.

[5] "Tiao" refers to the hierarchical authority and line management, that is, the vertical planning and management from the central ministries to the local agencies. "Kuai" based on function, refers to block management and horizontal planning of local governments at all levels (Lin & Xu, 2017; Wang, 2019).

vertical management reform of environmental protection agencies (VMR). This reform shifted the environmental management approach of the Ministry of Environmental Protection (MEP) from the territorial "block management" to the vertical "line-based, line-block-combined management." In the subsequent section, we will discuss the detailed differences between the previous "block management" and the approach under the VMR.

In the territorial management mode, government functional departments are usually in the charge of dual leadership of both the local government and the counterpart functional department at the higher level, where the local government is responsible for the affairs of "human resources, financial budget, and materials", while the counterpart functional department from the higher level responsible for "administrative power" only provides operational guidance. For example, the county-level EPB is under the direct management of the local county government, and the municipal-level EPB only provides operational guidance (as shown in Fig. 1).

Vertical management is a new mode in China's administrative system. In the vertical management mode, local governance is reduced as an intermediate process, and the central environmental protection policy could be implemented more directly and accurately. Under the VMR, the environmental functional departments are no longer managed by the local government, but are directly managed by the superior functional departments on the overall issues of "human resources, financial budget, materials, and affairs" in a unified manner. The county-level EPB, as the branch office of the municipal-level EPB, is no longer managed by the county government (as shown in Fig. 1). Thus, the management and control from the central government is strengthened, and the dynamics of lower-level environmental protection departments are more accurately grasped, so as to strengthen environmental supervision and effectively prevent and control environmental pollution.

The purpose of the VMR is to solve the four outstanding problems existing in the current local environmental management system dominated by "block", and the reform is aimed to adjust the local environmental protection management system and to construct three integrated systems, including environmental supervision system, environmental monitoring system, and environmental law enforcement system, which could be summarized as "concentrating supervision and monitoring powers (up to the province) and decentralizing law enforcement powers (down to the county)." More information on the reform could be found in the appendix.

To accurately collect the information of the VMR carried out by counties and it timing ever since the first implementation in counties of Tangshan City in 1992 to 2013, we resort to the following resources:

(1) Official documents of local governments, such as *the Directive for Reforming Environmental Protection Bureaus in Shaanxi Province* (issued by the government of Shaanxi Province on August 9, 2002);
(2) China Provincial and City Statistical Yearbook and local Chronicles, which record most important reform policies in China, such as Datong Statistical Yearbook, etc.;
(3) Chinese academic papers and books, such as Xuzhou City, Baotou City, Qiaodong District of Shijiazhuang City, and Qinhuangdao City, etc.;
(4) Official website of municipal-level EPB and prefectural/county People's Government. Annual reports of various working departments will be published in the column of Government Information Disclosure on the official website, from which it can be inquired the institutional changes of the county-level EPB;

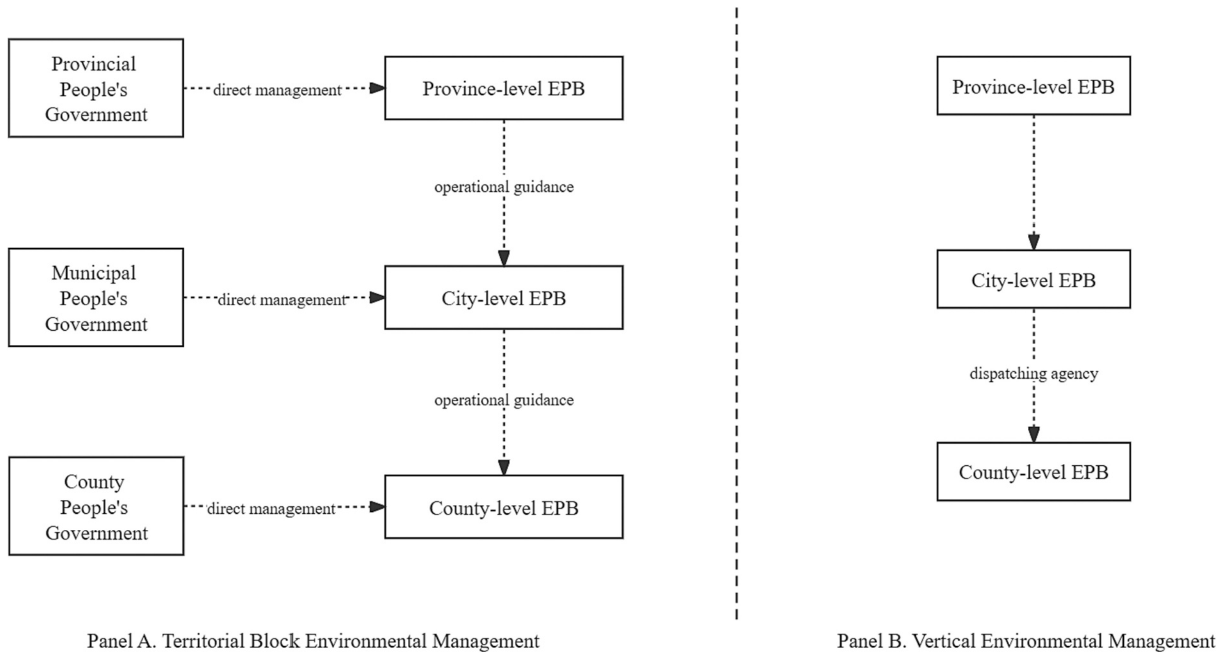

Fig. 1. Two types of environmental management mode.

(5) Network news and newspapers, such as Tieshan District of Huangshi City;
(6) The resume of the head of the environmental protection branch, such as Lubei District, Guye District, Fengrun District, and Lunan District, etc.;
(7) Direct phone call to the relevant local EPB for the few remaining counties, such as Qinbei District and Qinnan District of Qinzhou City, Xinzhou District of Shangrao City, etc. We also make phone call to other counties whose VMR information could be collected from the above ways to proofreading the policy information.

In sum, by the end of 2013, 118 prefecture-level cities in China had implemented the VMR, including 228 district-level EPBs and 95 county-level EPBs (Fig. 2), and we have mapped the counties where the VMR is implemented (Fig. 3).

4. Research design

4.1. Model specification

The staggered rollout of the VMR across different counties enables us to identify the causal effects of the vertical environmental management reform with the staggered DID model. The specification of the model is as follows:

$$y_{ict} = \beta_0 + \beta_1 VMR_{ct} + X_{it}^{'}\gamma + \left(\boldsymbol{Z}_{c,1999} \times \boldsymbol{\varphi}_t\right)^{'}\theta + \mu_i + \eta_{pt} + \lambda_{jt} + \varepsilon_{ict} \quad (1)$$

where the subscripts of i, c, p, j, and t indicate the individual firm, county, province, industry, and survey year, respectively. y_{ict} is the outcome variable, and in the benchmark model, we take the logarithm of pollutant emissions of firm i of county c in year t. VMR_{ct} is a dummy variable that equals 1 if the county c implements the vertical management reform in and after year t, and otherwise, 0. $\boldsymbol{X}_{it}$ is a vector denoting series of firm-level time-varying control variables, such as firm age and firm scale of assets. In addition, we include a series of control variables at county-level in 1999 before treated years, $\boldsymbol{Z}_{c,1999}$, interacted with time period fixed effects, φ_t, to flexibly capture potential differential changes across municipalities due to economic development level and population size, which may affect both the emission behaviors of firms and the implementation of the VMR. μ_i represents the firm fixed effect, which controls the impact of time-invariant firm characteristics; η_{pt} is the province-year fixed effect, which captures the provincial level characteristics changes over time; λ_{jt} is the industry-year fixed effect, which controls the impact of industry level changes over time; ε_{ict} is the error term, clustered at the county level. Thus, β_1 identified the causal effect of the VMR on outcome variables.

4.2. Data

4.2.1. Data at the firm level

We match the Annual Survey of Industrial Firms (ASIF) with the Environmental Survey and Reporting Database (ESR) to construct a large comprehensive dataset with detailed financial, production, pollution, and emission reduction facility investment information of firms from 1998 to 2013 as commonly used (Li, Jiang, Dong, & Dong, 2022). The ASIF database includes all state-owned firm and "above-scale" non-state firms ("above-scale" firms refer to firms whose sales are above 5 million yuan before 2011 and the sales threshold is raised to 20 million RMB since 2011) (Brandt, Van Biesebroeck, & Zhang, 2012; Fan, Lin, & Tang, 2018). The ESR database includes the top 85% firms of pollution source emissions in each county, which is ranked according to COD and sulfur dioxide (SO_2) emission levels, which has been used in many research (He, Wang, & Zhang, 2020; Qi, Zhang, & Chen, 2023; Zhang, Huang, & Qi, 2022). According to the geographical location of each firm and the latitude and longitude of the province, municipality, and county, the distance between the firm and each regional boundary can be calculated, and the minimum value of the distance is taken as the minimum distance between the firm and the administrative division boundary (provincial, municipal, and county boundary).

4.2.2. Data at the county level

The socio-economic data at county level comes from the 2000 China County Statistical Yearbook, the 2000 China Provincial Statistical Yearbook, and the 2000 China City Yearbook, including two kinds of indicators, GDP and total population at the end of the year. We have uniformly adjusted the administrative division codes of all counties to those of 2013.[6]

4.2.3. Data of Chinese political officials

The political official data is sourced from the Chinese Political Elite Database (CPED), a comprehensive biographical database encompassing Chinese political leaders from various levels. The data includes all prefectural party secretaries and mayors between 2000 and 2015, as well as provincial party secretaries and governors between 1995 and 2015 (Jiang, 2018). Besides, we complement the information regarding provincial/prefectural party secretaries for several years where CPED lacks data, to acquire political officials' data from 1998 to 2013.

[6] Administrative division code of 2013 is from the website of the Ministry of Civil Affairs (MCA) of China. https://files2.mca.gov.cn/cws/201404/20140404125552372.htm

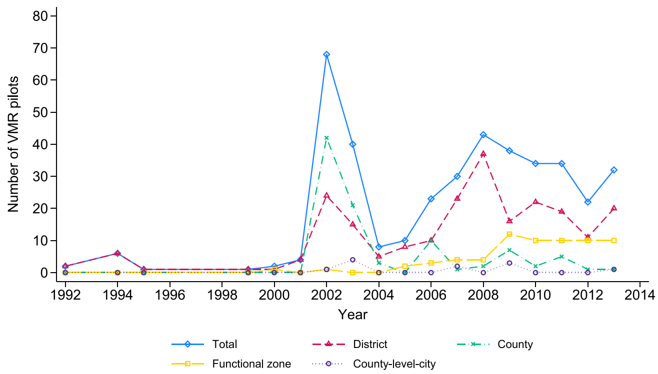

Fig. 2. The implementation of the VMR in various county-level administrative divisions during 1992–2013.

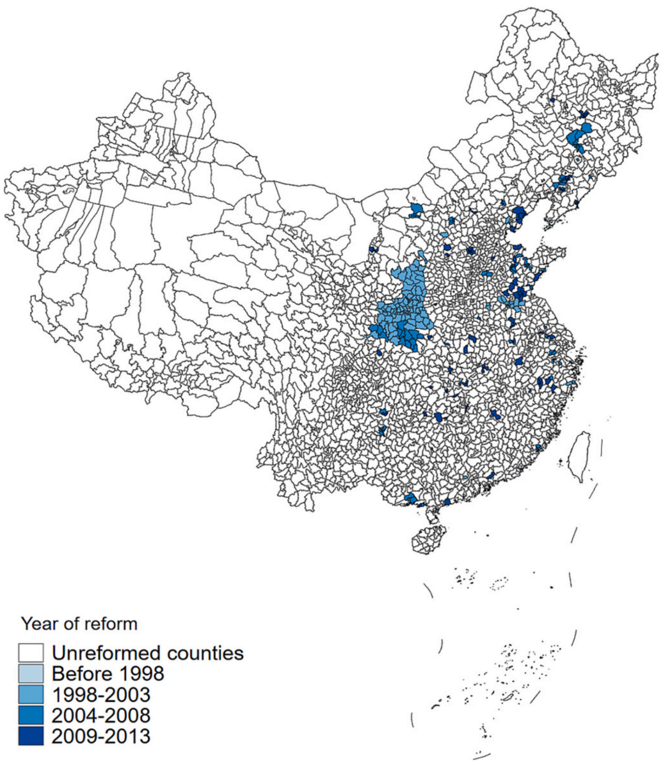

Fig. 3. The implementation of the VMR by 2013 at county-level.

4.2.4. Data clean

Firstly, the administrative division codes of 2013 are uniformly adopted, and the industry classification codes were adjusted according to the classification standard of 2002 (GB/T 4754-2002). Secondly, following Brandt et al. (2012), we link each year of data with the firms' names, unique numerical IDs, and addresses, etc., to form the longitudinal data and then match these data with county level conditions. Besides, to tackle with the price fluctuation, we use the producer price index in China Price Statistical Yearbook to calculate the annual base index and divide the total output value and other indicators into the base index to get the total output value of the final real value. Finally, we clean the data with the following steps (Yu, 2015):

(1) Drop observations that are obviously inconsistent with accounting principles, such as total assets less than current assets; The total assets are less than the net value of fixed assets; Total assets less than fixed assets; Some of the total assets, current assets, fixed assets, and main business (product sales) income are negative; Data whose gross output value is equal to zero;
(2) Drop observations with invalid definite times, e.g., opening month later than December or earlier than January;
(3) Drop observations in such counties with the VMR but no accurate reform time to be found, such as Haojiang District of Shantou City, Yucheng District of Heyuan City, and Jiangzhou District of Chongzuo City;

(4) Drop samples in such counties that have implemented policies before the sample period, such as Guye District and Lubei District of Tangshan, the municipal district of Dalian, and Tieshan District of Huangshi;
(5) Because the administrative divisions of municipalities directly under the central government are obviously different from those of other prefecture-level cities, these samples are excluded.

4.3. Variables and descriptive statistics

4.3.1. Dependent variables

We mainly focus on the impact of the VMR on water pollution with the following reasons. First, the VMR was initially launched in Shaanxi Province in 2002 due to the Hanjiang River water quality pollution incident occurred in Xunyang County of Ankang City. Second, since water resources are mostly related to production activities and economic development, combined with the technological limits, China has been strictly regulating COD emissions since the 1980s (Fan, Graff Zivin, Kou, Liu, & Wang, 2019; Zhang et al., 2018) instead of ammonia nitrogen (NH3-N) (He et al., 2020). In the benchmark model, we take the logarithm of COD. To explore how firms reduce emissions, we check the impact of the VMR on various factors, including gross output value, fresh water consumption per unit output value, the number of entering (exiting) firms, and entry and exit rates in passive approaches. Additionally, we assess the influence of the VMR on wastewater treatment capacity, both in general and at the level of individual facilities, in positive approaches. For further discussions, we focus on examining the impacts of the VMR on five distinct aspects through the following eight indicators: the logarithm of employees, investment decisions (whether to invest or not), the logarithm of investment, the logarithm of profit, the logarithm of export value, new green patent applications (whether there are new green patent applications or not), green invention patent applications, and the proportion of green patent applications among all patent applications.

4.3.2. Independent and control variables

The core explanatory variable of this paper is the VMR which is a dummy variable. If a county implements the VMR in a certain year, the value is 1 in that year and thereafter; otherwise, it is 0. In order to reduce the omitted variable bias, control variables are selected from the firm level and the county level, respectively. At the firm level, firm age (lnage) and firm scale of assets (asset) are controlled. At the county level, the social and economic indicators that may affect both the emission behaviors of firms and the implementation of the VMR are controlled, such as economic development level ($lnpgdp_{1999}$) and population size ($lnpop_{1999}$). To avoid estimation bias caused by bad control variables, this paper controls the county level socio-economic indicators in the initial year of research period, multiplied by the time dummies (Cinelli, Forney, & Pearl, 2022).

See Tables 1 and 2 for variable definitions and descriptive statistics, and Fig. 4 provides the industrial distribution difference between treatment and control groups.

5. Benchmark results

5.1. Effects of the VMR on reducing the emission of pollutants

Table 3 shows the impact of the vertical management reform on COD using Eq. (1). Column (1) presents the results with no control variables, column (2) controls county level variables, column (3) controls the firm level variables, and column (4) includes all control variables. All models in Table 3 control the firm fixed effect, province-year fixed effect, and industry-year fixed effect. Column (4) shows that, the VMR significantly reduces COD emissions of industrial firms by 22.94%. Besides, we inspect the impacts of the VMR on other pollutants (see Table B1) and find that the VMR has no significant impact on NH3-N. This lack of impact on NH3-N may be due to COD pollution originating from industrial wastewater, while NH3-N is mainly derived from agricultural pollution (Pan & Tang, 2021).

5.2. Test for parallel trend assumption

One of the basic assumptions of DID design to identify the causal effect of the VMR on firms' pollution emissions is the natural trend of treatment group and control group parallels. Referring to Beck, Levine, and Levkov (2010), we employ the event study design as Eq. (2) to test the assumption indirectly.

$$y_{ict} = \alpha + \sum_{k=-5,k\neq -1}^{5} \delta_k VMR_{ck} + \boldsymbol{X}_{it}^{'}\gamma + \left(\boldsymbol{Z}_{c,1999} \times \boldsymbol{\varphi}_t\right)^{'}\theta + \mu_i + \eta_{pt} + \lambda_{jt} + \varepsilon_{ict} \tag{2}$$

where k represents the relative years to the year of the VMR ($-5 \le k \le 5, k = -5 \text{ if } k \le -5, k = 5 \text{ if } k \ge 5$).

The estimation is shown in Fig. 5. Taking the year before the implementation of the VMR as the base period, the estimated coefficients of each period before the implementation of the policy are not significant, which meets the assumption of parallel trend. After the implementation of the policy, the coefficient is significantly different from zero, indicating that the vertical management reform has a significantly impact on the emission reduction of firms, and the estimated coefficient is still significantly negative after five years of the implementation of the reform, which means that the emission reduction effect of the VMR may not be temporary.

Table 1
Variable definitions.

Symbol	Definitions(unit)	Calculation
LnCOD	COD discharge(kg) with log form	$Ln(1+COD)$
VMR	Vertical management reform	Assign value according to the time of implementing vertical management reform in each county
$Lnpgdp_{1999}$	Level of economic development (10^4 Yuan) with log form	$Ln(1+\text{GDP per capita})$
$Lnpop_{1999}$	Population size (10^4 persons) with log form	$Ln(1+\text{Total population})$
Lnage	Firm age (year) with log form	$Ln(1+\text{Age})$
Lnasset	Firm assets (10^3 Yuan) with log form	$Ln(1+\text{Firm assets})$
Lnoutput	Total output value of firm (10^3 Yuan) with log form	$Ln\left(1+\frac{\text{Total industrial output price}}{\text{Base ratio index of the current year}}\right)$
Lnfresh_water_unit	Fresh water consumption per unit of output value (ton) with log form	$Ln\left(1+\frac{\text{Fresh water consumption}}{\text{Total industrial output price/base ratio}}\right)$
Ability	Wastewater treatment capacity (ton/day)	/
Ability_unit	Wastewater treatment capacity of individual facilities (ton/day)	$\frac{\text{Wastewater treatment capacity}}{\text{Number of wastewater treatment facilities}}$
Lnemploy	Average annual number of all employees (person) with log form	$Ln(1+\text{Average annual number of all employees})$
Invest	Whether firms will invest in fixed assets after the VMR	If yes, takes the value of 1; Otherwise, 0
Lninvest	Investment in fixed assets (10^3 Yuan) with log form	$Ln(1+\text{Investment in fixed assets})$
Lnprofit	Operating profit (10^3 Yuan) with log form	$Ln(1+\text{Operating profit})$
Lnexport_value	Export delivery value (10^3 Yuan) with log form	$Ln(1+\text{Export delivery value})$
Green_patent	Whether firms apply for green patents after the VMR	If yes, takes the value of 1; Otherwise, 0
Green_invent_patent	Invention green patent applications (based on principal classification number) (num)	/
Green_patent_rate	The share of invention green patent applications	$\frac{\text{Invention green patent}}{\text{Total number of patent applications}}$

Notes: In this paper, we add 1 before taking the logarithm, which serves to alleviate the influence of specific zero values.

5.3. Robustness checks

There may be still some potential threats in the baseline regression results, and the robustness of the benchmark results will be checked in this section.

5.3.1. Excluding counties with administrative division adjustment

The VMR can effectively reduce the emission of firms, but the adjustment of administrative divisions will alter the scope of policy implementation, thus induce changes in treatment group. For example, some counties may be merged into some certain county, or one county may be divided into several counties, such as some counties of Xuzhou, Nanjing, Tangshan, and Harbin, etc. To address the above concern, we use the subsample to limit our observations in the counties without administrative region adjustment during the sample period. With estimation of Eq. (1), columns (1) and (2) in Table 4 show that the results in the benchmark model still holds.

5.3.2. Excluding parent-subsidiary firms

The parent company may evade environmental regulations by redistributing production activities of subsidiaries (He et al., 2020), and then the effect of the VMR may just be the industrial spatial displacement rather than the emission reduction. Thus, we drop the samples of parent and subsidiary companies to tackle the threat, and the estimations are shown in columns (3) and (4) of Table 4.[7]

5.3.3. Placebo falsification

In order to test whether the basic conclusion is affected by missing variables and random factors, referring to Li, Lu, and Wang (2016), we conduct a placebo test and randomly assign each county to carry out the vertical management reform (VMR).[8] With this newly generated pseudo VMR variable, we run the regression with Eq. (1). In order to increase the accuracy of the identification of the placebo test, the above process was repeated 500 times. According to the random data generation process, the pseudo VMR variable should not produce a significant result.

Fig. 6 shows the cumulative distribution density of 500 times of point estimates and the baseline estimates −0.2294 (column (4) of Table 3). The random estimated distribution density is obviously centered on zero with the standard deviation of 0.094, and the baseline estimate is basically outside most of the distribution, indicating that the actual significantly positive impact of the VMR on reducing pollutant emissions is not random and not driven by unobserved factors.

[7] Following He et al. (2020), we identify parent and subsidiary companies based on the variable "parent company legal entity code" in the 2004 ASIF data.

[8] Table A2 shows that during the sampling period, the VMR has been carried out for 15 years.

Table 2
Descriptive statistics.

Variable	Full sample			Treatment group			Control group			Polluting industries			Non-polluting industries		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
LnCOD	427,228	7.045	3.940	46,851	7.018	3.966	380,377	7.048	3.937	203,676	8.312	3.610	32,378	6.135	3.297
$Lnpgdp_{1999}$	496,702	8.761	0.765	53,595	8.728	0.861	443,107	8.765	0.752	222,708	8.782	0.749	36,154	8.966	0.794
$Lnpop_{1999}$	496,702	3.921	0.635	53,595	3.737	0.660	443,107	3.943	0.628	222,708	3.959	0.626	36,154	3.957	0.644
Lnage	496,702	2.303	0.826	53,595	2.451	0.876	443,107	2.285	0.818	222,708	2.246	0.810	36,154	2.431	0.812
Lnasset	496,702	10.869	1.609	53,595	11.172	1.674	443,107	10.832	1.598	222,708	10.785	1.530	36,154	11.068	1.613
Lnoutput	479,065	6.088	1.698	52,078	6.369	1.748	426,987	6.054	1.689	221,751	6.108	1.657	36,062	6.373	1.764
Lnfresh_water_unit	344,980	4.764	2.380	39,171	4.547	2.260	305,809	4.792	2.393	164,995	5.301	2.363	25,880	3.716	1.996
Ability	325,114	3531.485	46,382.730	34,117	5181.965	79,114.110	290,997	3337.979	40,858.640	158,734	5459.504	59,799.400	21,450	528.441	4792.149
Ability_unit	260,451	2174.967	21,487.960	26,503	2429.678	25,652.610	233,948	2146.112	20,963.930	137,593	2842.578	19,927.430	16,169	507.969	4222.766
Lnemploy	490,903	5.510	1.132	53,074	5.725	1.195	437,829	5.484	1.122	220,372	5.385	1.117	35,935	5.754	1.149
Lninvest	140,247	7.740	2.770	15,638	7.991	2.862	124,609	7.709	2.757	65,246	7.682	2.711	9338	7.911	2.640
Lnprofit	343,566	7.776	2.500	35,811	7.972	2.614	307,755	7.753	2.485	154,047	7.680	2.474	25,774	7.842	2.475
Lnexport_value	387,725	2.667	4.562	44,484	2.566	4.484	343,241	2.680	4.572	175,234	2.579	4.475	30,056	4.945	5.303
Green_invent_patent	496,702	0.019	0.886	53,595	0.038	1.484	443,107	0.017	0.783	222,708	0.015	0.747	36,154	0.042	1.112
Green_patent_rate	38,314	0.023	0.117	5223	0.027	0.126	33,091	0.022	0.115	15,334	0.034	0.150	5165	0.011	0.068
Percent of Polluting Industries	86.03%			85.32%			86.12%								

Notes: Polluting industries and non-polluting industries are defined according to the proportion of COD emissions (Chen, Kahn, Liu, & Wang, 2018).

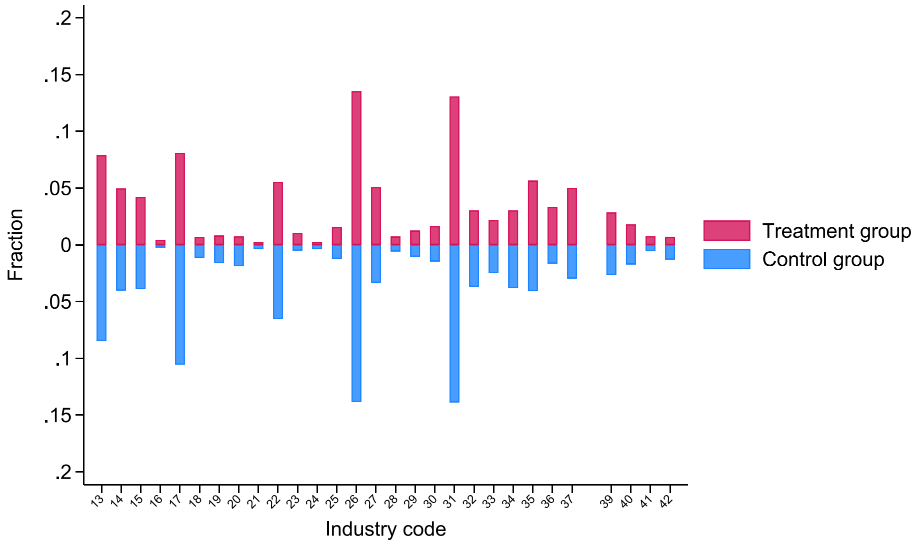

Fig. 4. Industrial distribution difference between treatment and control groups.
Notes: The figure shows the proportion of number of firms in different industries between treatment and control groups. There is no industry code 38 in the classification standard of 2002 (GB/T 4754-2002), and the corresponding name of each industry code is detailed in Table C1.

Table 3
The impact of the VMR on COD abatement.

	(1)	(2)	(3)	(4)
VMR	−0.2482**	−0.2449**	−0.2311**	−0.2294**
	(0.0992)	(0.0960)	(0.0992)	(0.0959)
Lnage			0.0799***	0.0783***
			(0.0182)	(0.0181)
Lnasset			0.1852***	0.1825***
			(0.0148)	(0.0147)
$Z_{c,1999} \times \varphi_t$	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Clusters	2203	2203	2203	2203
R^2	0.799	0.800	0.800	0.800
N	384,289	384,289	384,289	384,289

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. Singleton observations are dropped in the regressions with multi-levels of fixed effects. Maintaining the singleton observations may exaggerate statistical significance when the robust standard errors are clustered.

5.3.4. Robustness check for staggered treatment timing with heterogeneous treatment effect

According to Goodman-Bacon (2021), the two-way fixed effect estimator is equal to the weighted average of all possible two sets of DID estimators in the data. Thus, the DID estimation may be biased in staggered treatment timing with heterogeneous treatment effect if the group of differences between later treated and early treated accounts for too much. By using the method proposed by Goodman-Bacon (2021), we found that the treatment group and the untreated group accounts for the largest proportion, indicating that our estimate is unlikely to be biased (as shown in Fig. 7).

5.4. Heterogeneity analysis

5.4.1. Polluting and non-polluting industries

Referring to Chen, Kahn, et al. (2018), we divide our sample into polluting industries and non/less-polluting industries. The polluting industries are ferrous metal smelting and pressing, medical and pharmaceutical products, food production, beverage production, textile, chemical materials and products, agricultural products and byproducts, and pulp and paper production. As the main source of COD emissions in the manufacturing industry, the firms in these eight industries account for 2.58%, 3.04%, 3.31%, 6.45%, 6.74%, 13.13%, 15.1%, and 39.57% of the total COD emissions, respectively, and in all about 90%. Therefore, they may be the targets of monitoring and supervision by local environmental protection departments. There are nine non/less-pollution industries in total, including furniture manufacturing, cultural and sports manufacturing, office appliances manufacturing, printing, tobacco products,

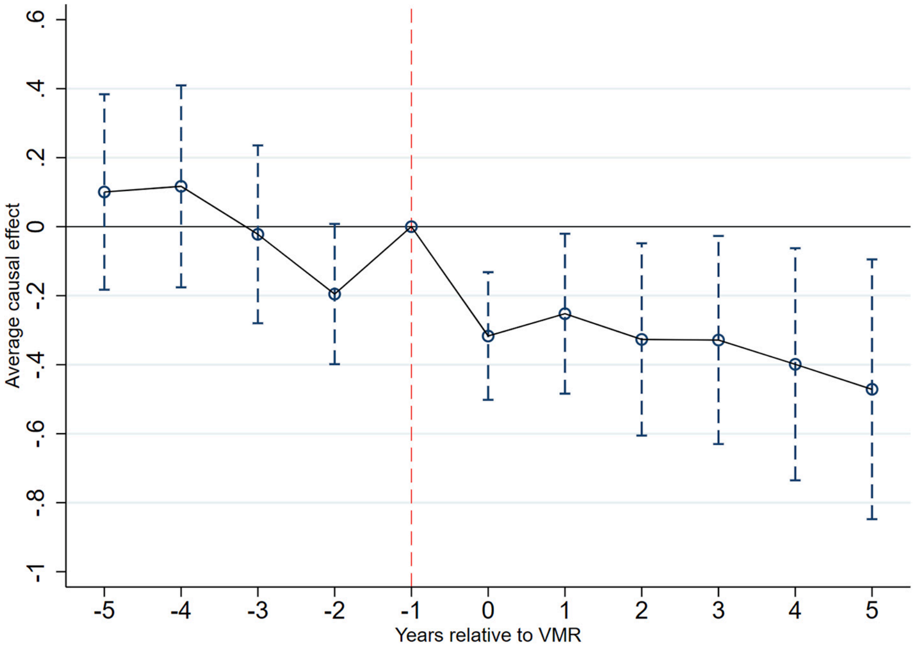

Fig. 5. Event study estimation.

Notes: The figure shows the event study graph for the main outcome variables on COD abatement. Each vertical line plots the estimated δ_k with 95% confidence intervals (CIs). The settings are the same as column (4) of Table 3.

Table 4

Robustness check of excluding counties with administrative zoning adjustment and parent-subsidiary firms.

	(1)	(2)	(3)	(4)
VMR	−0.2434** (0.1042)	−0.2210** (0.1016)	−0.2375** (0.1060)	−0.2193** (0.1010)
Firm Level Control	No	Yes	No	Yes
$Z_{c,1999} \times \varphi_t$	No	Yes	No	Yes
Firm FE	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Clusters	2143	2143	2203	2203
R^2	0.799	0.800	0.801	0.802
N	372,109	372,109	357,655	357,655

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The firm level control variables include firm age and asset as illustrated in Table 3. Other settings are the same as Table 3.

handicrafts manufacturing, plastic products, rubber products, and electric appliances manufacturing. These nine industries only account for a small part of the COD emissions of the manufacturing industry (no more than 1% in total) (Table C1).

The estimations are shown in columns (1) and (2) of Table 5, implying that the VMR effectively reduces the COD emissions of firms in polluting industries by 17.65%, and the regulation target of the VMR mainly lies in polluting industries.

5.4.2. *Firm scales*

In China, local governments usually follow a potential rule named "Grasp the Large, Let go of the Small" during regulations, which originated from the reform of state-owned firms (Hsieh & Song, 2015). "Grasp the Large" means relevant government policies and regulations are mainly aimed at large-scale firms, while "Let go of the Small" means that the government's regulations over small-scale firms are relatively weaker (He et al., 2020). This section will check whether this kind of control is applicable to regulations under the VMR. According to *China's Notice on Printing and Distributing the Interim Provisions on the Standards for Small and Medium sized Firms (GJMZZ [2003] No. 143)*, the large-scale firms are defined as the companies with no less than 300 employees, sales of no less than 30 million yuan, and total assets of no less than 40 million yuan, and the rest are small-scale firms. With regressions of the two groups as show in columns (3) and (4) of Table 5, it could find that the VMR has significantly reduced the COD emissions of large-scale firms by 20.56%, which is consistent with the general regulation and policy implementation strategy adopted by the local government of China.

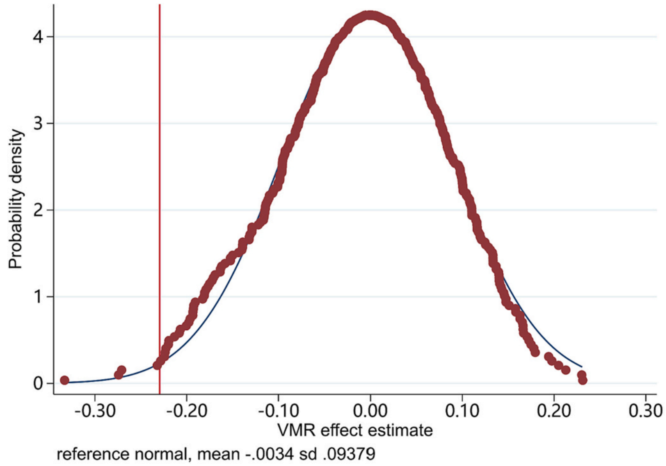

Fig. 6. Placebo test.
Notes: The figure shows the cumulative distribution density of the estimated coefficients obtained by randomly assigning 500 times of simulations of counties with VMR. The vertical bar represents the result for column (4) in Table 3.

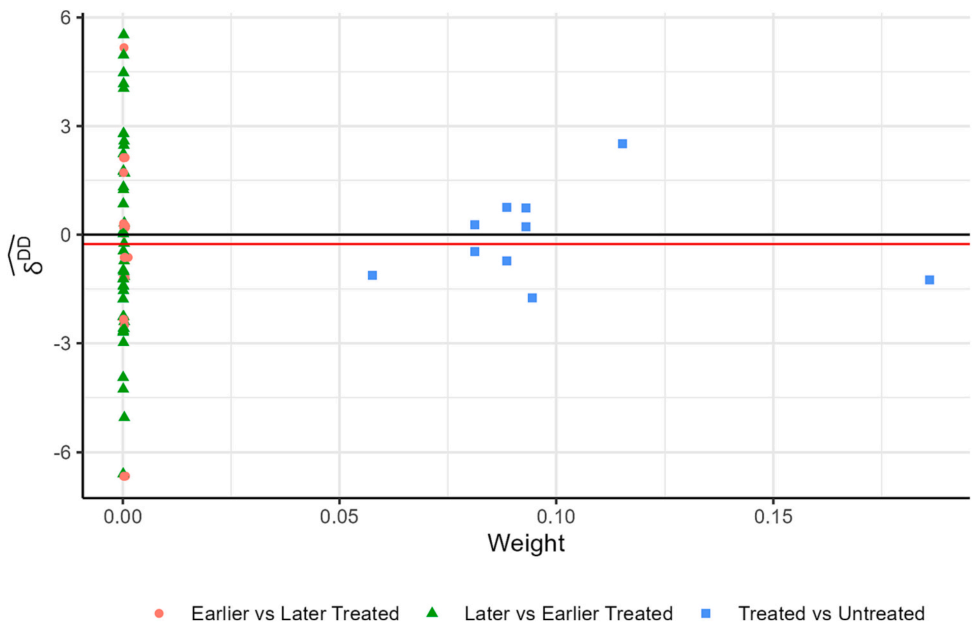

Fig. 7. Bacon decomposition.
Notes: The figure shows the results of the bacon decomposition, where the weight of the "Treated vs Untreated" group is 0.979, accounting for the largest proportion. The weights of the "Earlier vs Later treated" group and "Later vs Earlier treated" are 0.014 and 0.007, respectively.

5.4.3. Does the VMR help alleviate cross-border pollution

China has adopted many environmental regulatory policies to solve the currently unresolved problem of cross-border water pollution (Cai et al., 2016), but the effect is limited. Only by fundamentally improving China's environmental protection system can cross-border pollution be effectively addressed. The past territorial management mode has led to local governments acting independently. Due to the negative externalities of pollution, compared to border firms, the county government under the incentive of GDP assessment is more concerned about the environmental regulation of the central region where both taxes and environmental pollution are borne by the government. Therefore, stricter supervision is implemented for firms in the central region, while ignoring firms polluting the border (He et al., 2020).

According to the VMR content that the municipal-level (province-level) EPB uniformly manages the environmental problems of counties (municipalities) and the purpose of solving trans-regional and trans-basin environmental problems below the provincial level, we infer that after the reform, the regulation of county (municipal) boundaries will be strengthened, internalizing the boundary problem below the province, while the provincial boundaries will not be affected. The VMR may not have a significant impact on

Table 5
The VMR mainly affects polluting industries and large-scale firms.

	Polluting and non-polluting		Size	
	Polluting industries	Non-polluting industries	Big firm	Small firm
	(1)	(2)	(3)	(4)
VMR	−0.1765*	−0.1382	−0.2056*	−0.1668
	(0.0922)	(0.2877)	(0.1155)	(0.1068)
Firm Level Control	Yes	Yes	Yes	Yes
$Z_{c,1999} \times \varphi_t$	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Clusters	2133	1143	1944	2199
R^2	0.791	0.764	0.770	0.809
N	190,520	29,200	112,783	271,374

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The firm level control variables include firm age and asset as illustrated in Table 3. Other settings are the same as Table 3.

Table 6
VMR effects on firms at the border.

	Provincial boundary	Non-provincial boundary	Municipal boundary	Non-municipal boundary	County boundary	Non-county boundary
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Distance from boundary 5 km (≤5 km)						
VMR	−0.1812	−0.2484**	−0.2747**	−0.1943*	−0.2426**	−0.1017
	(0.2023)	(0.1046)	(0.1313)	(0.1101)	(0.1010)	(0.1618)
Panel B: Distance from boundary 10 km (≤10 km)						
VMR	−0.2266	−0.2715**	−0.2527**	−0.2268*	−0.2386**	0.1410
	(0.1825)	(0.1095)	(0.1238)	(0.1217)	(0.0978)	(0.3098)

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The settings are the same as column (4) of Table 3.

counties with stricter regulation before the reform, and the reduction of pollutants in the municipality mainly comes from the contribution of county boundaries, so its significance is relatively low. Table 6 validates our conjecture, which is one of the important achievements of our paper.

In Table 6, if the distance from the firm to the boundary (including provincial boundary, municipal boundary, and county boundary) exceeds 5 km in Panel A or 10 km in Panel B, the firm is located within the jurisdiction, otherwise located at the boundary. The columns (1) and (2) in Table 6 show that the VMR has a significantly negative impact on the pollutant emissions of firms located inside the province rather than at the provincial border. Columns (3) and (5) in Table 6 reflect that the VMR is conducive to promoting the emission reduction of firms at the municipal/county border. Taking 5 km in column (5) of Panel A as an example, the VMR can reduce about 24.26% of the COD emissions of firms at the county boundary. Besides, the column (4) in Table 6 shows that the VMR also has a significantly negative effect on firms located inside the municipality.

5.4.4. *The political incentives and emission-reduction effect*

The promotion of local officials is closely related to the quality of environment in the area under their jurisdiction (Tang et al., 2021). Under the local political promotion criteria, local officials will have more incentives to implement central environmental policies to reduce polluting for their promotion, but once they have weak incentives to promote, the motivation of local officials to implement environmental policies will be greatly reduced. In this section, we check the impacts of local officials' promotion incentives at various levels on the effect of the VMR on emission reduction.[9]

The party secretary is the leader of the local party committee, who is the top-ranked official in the local government mainly responsible for local party affairs, personnel arrangements, and project work (Kahn et al., 2015). According to Kou and Kou and Tsai (2014) and He et al. (2020), the provincial party secretary younger than 63 has a higher probability of being promoted, but the promotion opportunity beyond that age is greatly reduced, which may greatly reduce the incentives of provincial party secretary to implement central government policies. And the age threshold for prefectural party secretary is 57 years old. With the age threshold of

[9] We thank the referee for the suggestion of this part.

Table 7
The impacts of political incentives from government officials at different levels on the emission-reduction effect.

	Provincial official		Prefectural official	
	Younger than 63 years old	Older than 63 years old	Younger than 57 years old	Older than 57 years old
	(1)	(2)	(3)	(4)
VMR	−0.2082*	−0.3394	−0.2235**	0.1779
	(0.1079)	(0.2219)	(0.1045)	(0.1932)
Firm Level Control	Yes	Yes	Yes	Yes
$Z_{c,1999} \times \varphi_t$	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes
Clusters	1997	1361	1957	886
R^2	0.809	0.870	0.807	0.902
N	289,744	53,473	289,588	39,405

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The firm level control variables include firm age and asset as illustrated in Table 3. Other settings are the same as Table 3.

promotion, we analyze the impacts of political incentives from provincial and prefectural party secretaries on the emission-reduction effect of the VMR.[10]

The columns (1) and (2) in Table 7 show the heterogeneous effects of emission-reduction of the VMR at the provincial level. When the provincial party secretary is less than 63 years old with strong promotion incentives, the effect of the VMR is significantly negative, which will reduce the COD emissions of firms by 20.82%, while in the counterpart group, the effect is insignificant. The columns (3) and (4) in Table 7 show the heterogeneous impacts at the prefectural level. Prefectural party secretary younger than 57 years old has strong incentives to implement central government policies, which will reduce the COD emissions of firms by 22.35%.

6. Pollution reduction channels

Typically, polluting firms reduce emissions in two approaches under environmental regulation. One is the passive approach, by changing production ("changes in process"), firms could reduce the generation of pollutants from the production side, such as simply cutting production or directly shutting down. The other is the positive approach, that is, at the end of the production, firms could use pollution treatment equipment to remove the generated pollutants or reduce their emission concentration ("end of pipe").

6.1. *Abatement by passive approaches*

6.1.1. *Production reduction*

The gross output value can reflect the firm's production scale, and water also plays as an important input in many production processes. More water consumption is also related to more wastewater discharge and pollutant discharge (He et al., 2020). Thus, the larger the production scale is, the more the water consumption is, and the higher the water pollutant discharge is.

As shown in Table 8, it could be found that the VMR has a significantly negative impact on the gross output value of firms in all industries and polluting industries and will reduce the use of fresh water consumption per unit output value of firms in polluting industries, thus reducing pollution discharge, while the approach does not hold in the non/less-polluting industries. This could play as a relatively mild passive approach.

6.1.2. *Firm shut down*

Besides, there is still another enforcement of the VMR in the rudimentary form, that is, shutting down firms or raising barriers to entry.

The first concern in this regard is to identify the entry and exit condition. Since the annual sales threshold for the above-scale non-state-owned firms in ASIF is 5 million RMB, while after 2011, the designated "above-scale" is raised to 20 million RMB (Fan et al., 2018), and it could potentially mix up the actual dynamics of market entry and exit with just changes in statistical method. To avoid the estimation bias caused by the changes in statistical caliber, we use the business registration information of industrial firms in the National Enterprise Credit Information Publicity System (NECIPS) which precisely records the firm's cancellation and revocation time (if the firm has been canceled or revoked) to combine with ASIF.[11] With this dataset, we calculate the number of firm entry and exit, which will efficiently avoid the estimation bias caused by the increase in the "above-scale" after 2011 in ASIF. Referred to Barwick, Chen, Li, and Zhang (2022), the number of entering (exiting) firms, and entry and exit rates are calculated by different sample groups

[10] The political officials data is from Chinese Political Elite Database (CPED) which contains information on multiple levels of political leaders (Jiang, 2018), and we supplemented the missing data in the CPED to obtain information on provincial/prefectural party secretary from 1998 to 2013.

[11] The new dataset includes 88.37% of our original sample.

Table 8
Production reduction.

	All industries		Polluting industries		Non-polluting industries	
	(1)	(2)	(3)	(4)	(5)	(6)
	Lnoutput	Lnfresh_water_unit	Lnoutput	Lnfresh_water_unit	Lnoutput	Lnfresh_water_unit
VMR	−0.0412*	−0.0497	−0.0523*	−0.1228***	0.0293	−0.0987
	(0.0226)	(0.0387)	(0.0275)	(0.0460)	(0.0627)	(0.1217)
Firm Level Control	Yes	Yes	Yes	Yes	Yes	Yes
$Z_{c,1999} \times \varphi_t$	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clusters	2205	2193	2146	2110	1209	1047
R^2	0.924	0.835	0.917	0.854	0.942	0.827
N	447,116	312,923	208,018	150,919	32,687	22,780

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The firm level control variables include firm age and asset as illustrated in Table 3. Other settings are the same as Table 3.

of all, polluting, and non-polluting industries, respectively, in each county and year.

We take the logarithm of the number of new entrants in each county and year to calculate the entry number and define entry rate as the ratio of entrants to lagged incumbents multiplying 100 in logarithm. Lagged incumbents are the number of firms operating until last year in each county and year. For firms shutting down, we also calculate two indicators, that is, the exit number which is the number of firms being revoked or canceled in each county and year, and the exit rate which is designed as the ratio of exit number to lagged incumbents multiplying 100 in logarithm.

Table 9 column (1) shows that the VMR will reduce the number of new entrants by 13.62% in average. As shown in columns (5)–(8) of Table 9, the implementation of the VMR significantly decreases the number of firms' entry, increases the number of firms' exit and leads to about 6.0% increase in exit rate in polluting industries, which help to reduce the pollutant emissions in a crude manner.

6.2. Abatement by positive approaches

In the positive way, the number of wastewater treatment facilities cannot accurately reflect the capability of a firm wastewater treatment (Wang & Xiong, 2022), so we use wastewater treatment capacity and wastewater treatment capacities of individual facilities as the independent variables to check the positive approaches of emission reduction. Wastewater treatment capacity refers to the daily tons of wastewater treatment firms, and wastewater treatment capacity of individual facilities is the average treatment capacity calculated based on the number of wastewater treatment facilities.

The estimation in column (4) of Table 10 shows that the VMR significantly improves the wastewater treatment capacity of individual facilities, but do not improve the overall the wastewater treatment capacity of a firm, indicating that regulations may be implemented by the requirements of governments to meet the treatment facility capacity standards, which is usually known as command-type environmental regulation based on technical standards. However, as the estimations implying, this kind of regulation may be inefficient, since the overall treatment capacity of a firm is not increased.

7. Further discussions

To check the subsequent social and economic impacts of the VMR, we mainly focus on the following aspects, that is, the employment, investment, firm profitability, market competitiveness, and innovation in all industries, the polluting industries, and non-polluting industries, respectively. For the investment, we adopt two measurements, whether to invest or not and the logarithm of investment. In regard to market competitiveness, we use the logarithm of export value as the proxy. For innovation, we consider new patent applications, including whether to have new green patent applications or not, green invention patent applications, and the share of green patent applications in all patent applications.[12]

Table 11 shows that the VMR will significantly reduce the employment by 3.99% in column (1) Panel A, lower the investing probability by 36.08 percentage points in column (2) Panel A, weaken the export competitiveness and decrease the export value by 14.33% in column (5) Panel A, while has insignificant impacts on the total amount of investment and profitability.

In terms of innovation, the VMR has significantly increased the probability of green patent applications by 3.10 percentage points in column (1) Panel A, but has an insignificant impact on green invention patent applications, as well as the share of green patents, as shown in Table 12.

[12] According to the list of green patent Classification Scope provided by WIPO (World Intellectual Property Organization), green patents are screened by main classification number or classification number. There are three types of patent in China, namely invention patent, utility model patent, and the appearance design patent, among which invention patent can represent patent quality (Tan, Zhang, & Cao, 2023).

Table 9
The impacts of the VMR on firm entry and exit.

	All industries				Polluting industries				Non-polluting industries			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Lnentry_num	Lnentry_rate	Lnexit_num	Lnexit_rate	Lnentry_num	Lnentry_rate	Lnexit_num	Lnexit_rate	Lnentry_num	Lnentry_rate	Lnexit_num	Lnexit_rate
VMR	−0.1362***	−0.0429	0.0178	0.0159	−0.0853***	−0.0613	0.0279***	0.0623**	−0.0160	0.0572	−0.0076	−0.0327
	(0.0322)	(0.0466)	(0.0147)	(0.0223)	(0.0243)	(0.0522)	(0.0088)	(0.0243)	(0.0157)	(0.0562)	(0.0072)	(0.0339)
$Z_{c,1999} \times \varphi_t$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clusters	2200	2199	2200	2199	2106	2104	2106	2104	1138	1137	1138	1137
R^2	0.589	0.409	0.247	0.131	0.443	0.292	0.180	0.108	0.345	0.215	0.117	0.088
N	32,296	32,191	32,296	32,191	31,254	30,328	31,254	30,328	17,112	15,015	17,112	15,015

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The samples are from 1998 to 2013 at the county level, including about 2100 counties. Singleton observations are dropped in the regressions with multi-levels of fixed effects. Maintaining the singleton observations may exaggerate statistical significance when the robust standard errors are clustered.

Table 10
The impact of the VMR on firms' capacity of wastewater treatment facilities.

	All industries		Polluting industries		Non-polluting industries	
	(1)	(2)	(3)	(4)	(5)	(6)
	Ability	Ability_unit	Ability	Ability_unit	Ability	Ability_unit
VMR	3076.717	526.605	5696.507	1346.262*	517.311	252.586
	(2180.335)	(666.657)	(3787.316)	(795.526)	(679.734)	(282.485)
Firm Level Control	Yes	Yes	Yes	Yes	Yes	Yes
$Z_{c,1999} \times \varphi_t$	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clusters	2183	2122	2077	1992	957	777
R^2	0.576	0.435	0.628	0.589	0.534	0.434
N	290,425	231,871	148,131	128,792	19,254	14,575

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The firm level control variables include firm age and asset as illustrated in Table 3. Other settings are the same as Table 3.

Table 11
Effects of the VMR in terms of employment and profitability.

	(1)	(2)	(3)	(4)	(5)
	Lnemploy	Invest	Lninvest	Lnprofit	Lnexport_value
Panel A: All Industries					
VMR	−0.0399**	−0.3608***	−0.0339	−0.0415	−0.1433*
	(0.0176)	(0.0278)	(0.1349)	(0.0768)	(0.0786)
Panel B: Polluting Industries					
VMR	−0.0447**	−0.3425***	0.1105	−0.1143	−0.0989
	(0.0204)	(0.0292)	(0.1549)	(0.0881)	(0.0960)
Panel C: Non-polluting Industries					
VMR	0.0338	−0.4210***	0.5207	0.3668	0.4329
	(0.0537)	(0.0596)	(0.4664)	(0.2461)	(0.4016)

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The settings are the same as column (4) of Table 3.

Table 12
Effects of the VMR in terms of innovation.

	(1)	(2)	(3)
	Green_patent	Green_invent_patent	Green_patent_rate
Panel A: All Industries			
VMR	0.0310***	0.0113	−0.0088
	(0.0035)	(0.0152)	(0.0077)
Panel B: Polluting Industries			
VMR	0.0240***	0.0089	−0.0220
	(0.0036)	(0.0201)	(0.0141)
Panel C: Non-polluting Industries			
VMR	0.0266***	0.0606	−0.0171
	(0.0097)	(0.0646)	(0.0149)

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The settings are the same as column (4) of Table 3. We also do all the green patents and all the patents, but none of them are significant. Due to space constraints, it is not shown, but requested.

8. Conclusion

Decentralization grants autonomy to local governments to promote economic development, but often disregards environmental pollution control and its spillover effects. In contrast, centralization achieves these objectives by imposing stricter regulations on local governments. We provide evidence in support of this argument by examining the impact of vertical management reform of China's environmental protection agencies (VMR).

Using the combined data of ASIF and ESR from 1998 to 2013, this paper investigates the causal effect of the VMR on firms' pollution reduction by the staggered difference-in-differences method. The findings reveal several insights. First, the VMR significantly reduces approximately 22.94% of COD emissions from firms. Second, the impacts of the VMR on polluting industry, large-scale firms, and firms located at administrative borders are more pronounced, aligning with local government strategies where strong promotion significantly influences the emission-reduction effect. Third, the emission reduction targets of the VMR are achieved through passive approaches, such as cutting down production, reducing firms entering, and increasing firms exiting rate, as well as proactive measures to enhance wastewater treatment capacities in individual facilities. Finally, the costs of the VMR are evident as it significantly diminishes employment, investment efficiency, and export competitiveness of firms. Furthermore, although VMR increases the probability of green patent applications, it displays insignificant impacts on green invention patent applications.

The paper verifies the advantages of environmental centralization represented by vertical management reform in addressing environmental pollution. The VMR serves as a highly effective initiative that delineates the responsibilities of local governments and environmental protection departments, strengthens firm regulation, and mitigates local protectionism to some extent through the environmental supervision system. It significantly impacts firms' pollutant discharge. However, due to the information asymmetry inherent in the centralized institution, this reform is still associated with relatively high economic costs, suggesting a need for more precise environmental regulation. In environmental policy, beyond the convenience of policy implementation, economic costs should also be considered.

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Declaration of competing interest

No conflict of interests.

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Data availability

The data that has been used is confidential.

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The conclusions, opinions, and views expressed by authors in this paper are the authors' conclusions, opinions, and views.

Appendix A. Details of vertical management reform of environmental protection agencies (VMR)

The Tiao-Kuai (literally line and block) system constitutes the basis of Chinese political governance. "Tiao" refers to the hierarchical authority and line management, that is, the vertical planning and management from the central ministries to the local agencies. "Kuai" based on function, refers to block management and horizontal planning of local governments at all levels (Lin & Xu, 2017; Wang, 2019). Under the Tiao-Kuai management, China's environmental protection management system presents the characteristics of regional segmentation and decentralized (Han & Tian, 2022). Previously, the establishment, personnel, and funding of local environmental protection agencies were all in the charge of local governments, generally taking the mode of "block management", which in return leaded to economic development at the expense of the environment and local government intervention in environmental monitoring, supervision, and law enforcement (Han & Tian, 2022). In the past, China's environmental regulations were mainly targeted at the environmental violations of firms (Zhang et al., 2018). From the side of "line system", there was a lack of supervision over local EPBs and local governments, and follow-up reward and punishment system arrangements.

Thus, in order to strengthen the role of local EPBs in environmental protection and clarify the responsibilities of local governments, some counties in Tangshan city carried out vertical management reform of environmental protection agencies (VMR) in 1992. In August 2002, Shaanxi Province issued *the Directive for Reforming Environmental Protection Bureaus in Shaanxi Province* and embarked on the environmental vertical management reform. Later on, counties and districts successively carried out the VMR. Finally, the central government of China issued *the Guidelines for the Pilot Program for the Vertical Management Reform of Environmental Monitoring, Inspection and Law Enforcement below the Provincial Level* on September 22, 2016, which marks the implementation of the vertical management reform of environmental protection agencies (VMR) at national level.

The VMR adjusts the environmental management mode of the Ministry of Environmental Protection (MEP) from territorial "block management" to the vertical "line-based, line-block-combined management", where "line" refers to the environmental protection system, under which the environmental supervision responsibilities of province-level EPB and the environmental law enforcement and firm inspection responsibilities of the municipal-level EPB will be strengthened; And "block" refers to local governments, under which the environmental protection responsibilities of local governments and related departments have been clarified through the establishment of environmental protection committees and the formulation of responsibility lists,[13] which is reflected in the form that the county-level EPB has been changed into the environmental protection branch of municipal-level EPB. To avoid the situation that local governments would not fulfill their responsibilities and strengthen the supervision of local EPBs and governments, the VMR also defines two basic functions of environmental regulation (supervision) for the first time, one is to enforce the environmental law on firms and public agencies and other administrative counterparts, and the other is the supervision of lower levels of governments and their work departments.

The purpose of the VMR is to solve the four outstanding problems existing in the current local environmental management system dominated by "block": (1) Difficulties to implement the supervision responsibility of local governments and their related departments; (2) Difficulties to solve the interference of local protectionism on environmental monitoring, supervision, and law enforcement; (3) Difficulties to adapt to the coordinating and solving trans-regional and trans-basin environmental problems; (4) Difficulties to standardize and strengthen the construction of local environmental protection organizations.

The process of reform is carried out from six aspects, that is, strengthening the environmental protection responsibility of local Party committees and governments, adjusting the local environmental protection management system, standardizing and strengthening the construction of local environmental protection organizations and teams, establishing the sound, efficient, and coordinated operating mechanism, implementing reform-related policies and measures, and enforcing the organizational implementation. The focus of reform is on adjusting the local environmental protection management system and constructing three systems, including environmental supervision system, environmental monitoring system, and environmental law enforcement system, which can be summarized as "concentrating supervision and monitoring powers (up to the province) and decentralizing law enforcement powers (down to the county)." Table A1 shows more details of core content of vertical management reform.

The environmental supervision system strengthens the supervision of province-level EPB over the performance of lower-level EPBs and carries out serious accountability to those responsible for ineffective performance of duties, namely, "Du Zheng" (literally government inspection). The environmental monitoring system ensures the authenticity and effectiveness of environmental monitoring data. The environmental law enforcement system has decentralized the law enforcement downward county-level. Each county is authorized by the municipal-level EPB to inspect firms and impose strict law enforcement and administrative penalties on environmental violations of firm.[14]

Table A1
Main contents of vertical management reform.[a]

Aspect		Province-level EPB	Municipal- level EPB	County- level EPB	Phone Supplement
Management system of environmental protection agencies		/	Dual management dominated by the province-level EPB.	Be adjusted into a branch of and be directly managed by the municipal-level EPB.	/
Environmental supervision system		The environmental monitoring functions of the municipal-level and county-level EPB will be taken over and exercised by the province-level EPB in a unified manner. The province-level EPB will establish accredited agencies for environmental monitoring in cities or cross-municipal and county regions.			/
Environmental monitoring system	Within the jurisdiction	Responsible for the monitoring, investigation, evaluation and assessment of ecological environmental quality	Be transformed into municipal environmental monitoring agencies under the direct management of province-level EPB.	For counties without environmental monitoring agencies at present, the task of environmental monitoring shall be undertaken by municipal-level EPB integrating existing county environmental monitoring agencies, or assisted by municipal environmental monitoring agencies.	Local EPBs monitor firms, and each branch has a "law enforcement inspection + supporting law enforcement" system which the municipal-level EPB system can view; At the same time, the branch also needs to report upwards, as does the municipal-level EPB.
	Trans-regional and *trans-*	Select environmental monitoring agencies based in cities with strong	Integrate and set up cross-municipal environmental law	/	For cross-regional pollution problem, if reported, the territorial department is

(*continued on next page*)

[13] From China Environment News: http://epaper.cenews.com.cn/html/2016-09/28/content_50626.htm (in Chinese).

[14] After the VMR, each county-level EPB is a branch of the municipal-level EPB. Only with the authorization of laws and regulations can it implements administrative punishment on its own. Therefore, the municipal-level EPB is the administrative organ within the jurisdiction that has the power of administrative punishment for violations of the ecological environment.

Table A1 (*continued*)

Aspect		Province-level EPB	Municipal- level EPB	County- level EPB	Phone Supplement
	watershed issues	comprehensive capabilities to undertake the function of cross-regional and cross-watershed ecological environmental quality monitoring.	enforcement and environmental monitoring agencies.		directly responsible for handling; If it is found by the local EPBs, the connection between regions will be carried out, and one of the regional sub-bureaus will take the lead and all sub-bureaus will jointly handle the problem.
Law enforcement system		Give guidance to subordinate agencies, and investigate and handle cross-municipal disputes and major cases.	(1) Responsible for territorial environmental law enforcement; (2) Manage and direct the subordinate agencies.	Existing environmental protection permits and other functions should be handed over to municipal-level EPB, and part of the specific work of environmental protection permits should be undertaken within the scope authorized by municipal-level EPB.	(1) In terms of the intensity of punishment, county-level law enforcement departments have the function of punishment and punish firms in accordance with relevant laws and regulations; (2) In terms of law enforcement, each county branch has its own law enforcement detachment, which is under the administration of the municipal-level EPB, and its law enforcement is authorized and allocated by the municipal-level EPB.

[a] Detailed information is available upon request.

Table A2
Number of counties adopting the VMR.

Year	VMR
Before 1998	9
1998	0
1999	1
2000	1
2001	4
2002	67
2003	40
2004	8
2005	8
2006	20
2007	26
2008	39
2009	26
2010	24
2011	24
2012	12
2013	22
Total	331

Appendix B. Other relevant regression results

Table B1
Impacts of the VMR on other pollutant abatement.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	LnCOD	Lnwater	LnNH3-N	Lngas	LnSO_2	LnNO_x	Lnds	Lnsoot	Lndust
VMR	−0.2294**	−0.1387*	−0.0626	−0.0069	−0.0176	0.2179	−0.0643	0.1319	0.1598
	(0.0959)	(0.0730)	(0.1577)	(0.0555)	(0.0665)	(0.1394)	(0.0635)	(0.1205)	(0.1535)
Firm Level Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$Z_{c,1999} \times \varphi_t$	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

(*continued on next page*)

Table B1 (*continued*)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	LnCOD	Lnwater	LnNH3-N	Lngas	$LnSO_2$	$LnNO_x$	Lnds	Lnsoot	Lndust
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clusters	2203	2202	2178	2189	2198	2125	2197	2189	2181
R^2	0.800	0.795	0.795	0.856	0.827	0.844	0.861	0.798	0.900
N	384,289	391,370	260,546	290,373	372,841	189,729	293,894	274,063	214,581

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. Robust standard errors clustered at the county level are in parentheses. The pollutants in each column from left to right are COD (LnCOD), wastewater (Lnwater), ammonia-nitrogen (LnNH3−N), waste gas (Lngas), sulfur dioxide ($LnSO_2$), nitrogen oxide ($LnNO_x$), soot and dust (Lnds), soot (Lnsoot), dust (Lndust). All dependent variables are treated with taking the nature logarithms of which adding one. The firm level control variables include firm age and asset as illustrated in Table 3. Other settings are the same as Table 3.

Appendix C. Standards to divide polluting and non-polluting industries

Table C1
COD emission ratio of each manufacturing industry.[a]

Two-digit industry code	Two-digit industry	Industrial COD discharge proportion
21	**Furniture manufacturing**	**0.02%**
24	**Cultural and sports appliances**	**0.02%**
41	**Office appliances manufacturing**	**0.03%**
23	**Printing**	**0.06%**
16	**Tobacco products**	**0.09%**
42	**Handicrafts manufacturing**	**0.16%**
30	**Plastic products**	**0.17%**
29	**Rubber products**	**0.17%**
39	**Electric appliances manufacturing**	**0.23%**
34	Metal products	0.27%
36	Special appliances manufacturing	0.31%
18	Garments manufacture	0.31%
40	Electronic appliances manufacturing	0.32%
35	General appliances manufacturing	0.32%
20	Processing of wood, bamboo, and straw	0.44%
37	Transportation appliances manufacturing	0.47%
33	Non-ferrous metal smelting and pressing	0.67%
31	Non-metal mineral products	0.92%
25	Petroleum and nuclear fuel processing	1.49%
19	Leather, furs, feathers and related products	1.52%
28	Chemical fiber	2.10%
32	**Ferrous metal smelting and pressing**	**2.58%**
27	**Medical and pharmaceutical products**	**3.04%**
14	**Food production**	**3.31%**
15	**Beverage production**	**6.45%**
17	**Textile**	**6.74%**
26	**Chemical materials and products**	**13.13%**
13	**Agricultural products and byproducts**	**15.10%**
22	**Pulp and paper production**	**39.57%**

[a] The bold font in the upper part of the table indicates non-polluting industries and the bold font in the lower half indicates polluting industries

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