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# The Impact of the Vertical Management Reform of Environmental Protection Agencies on Firms' Total Factor Productivity

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**Abstract**

This paper treats the 2016 reform of the vertical management of environmental protection agencies as a quasi-natural experiment. Using data from Chinese A-share-listed companies on the Shanghai and Shenzhen stock exchanges from 2012 to 2022, we employ a multi-period difference-in-differences (DID) approach to examine the impact of environmental governance structural reforms on firms' total factor productivity (TFP). The study finds that the vertical management reform of environmental protection agencies significantly suppressed TFP in pilot regions. This conclusion remains valid after robustness tests, including parallel trend tests, placebo tests, PSM-DID, alternative TFP estimation methods, and the exclusion of contemporaneous policy disturbances. Mechanism tests suggest that the reform may affect firm productivity by weakening firms' technological innovation capabilities and reducing capital allocation efficiency; further green innovation tests did not find a significant innovation compensation effect. Heterogeneity analysis indicates that this negative impact is more pronounced in state-owned enterprises, firms subject to weaker regulation, and firms in the eastern region. This paper extends research on the economic consequences of environmental policies from traditional regulatory instruments to the level of environmental governance structural reforms, providing micro-level empirical evidence for understanding the relationship between environmental governance reforms and firm efficiency.

**Keywords:** vertical management reform; environmental protection; firm-level total factor productivity (TFP); difference-in-differences (DID); green development

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## 1. Introduction

Total Factor Productivity (TFP), widely regarded as a central measure of firms' efficiency in resource allocation and their capacity for innovation, has emerged as a fundamental driver of high-quality economic growth at the national level (Pan et al., 2022) [1]. TFP is defined as the portion of output that cannot be explained by capital and labor inputs, reflecting both technological progress and efficiency improvements (Solow, 1957) [2]. For firms, gains in TFP are reflected not only in higher output efficiency but also in enhanced managerial effectiveness, improved organizational design, the adoption and diffusion of technological innovation, and more efficient resource allocation (Bender et al., 2018; Bloom et al., 2019) [3,4]. Given its multidimensional nature, the determinants of TFP are inherently complex and multifaceted (Autor et al., 2020) [5]. The determinants of TFP reflect both

internal and external dimensions. Internally, governance structures, organizational design, technological progress, and human capital accumulation shape the efficiency with which resources are utilized (Cammeraat et al., 2024; Lei et al., 2025) [6,7]. Externally, institutional arrangements, policy environments, and socio-ecological constraints play a critical role in shaping firms' productivity outcomes (Kafouros et al., 2024) [8]. As the pursuit of balanced environmental protection and economic growth intensifies, firms aiming for long-term development can no longer concentrate solely on internal governance efficiency or the narrow expansion of productivity. Rather, they must incorporate the broader institutional, policy, and ecological context into their strategic considerations, recognizing the profound influence of social responsibility and external constraints on productivity (Baker et al., 2016) [9]. Moreover, treating TFP as the sole benchmark of corporate development is overly narrow. Firms should not only strive for efficiency gains but also align their strategies with broader goals of social responsibility and sustainable development (Edmans, 2023; Ioannou and Serafeim, 2015) [10,11]. Against this backdrop, environmental protection policies, as critical external institutional arrangements, have emerged as an increasingly important force shaping firms' Total Factor Productivity.

Regarding the relationship between environmental regulations and firm productivity, existing research has not reached a unanimous conclusion but has instead yielded two competing explanations: the "compliance cost effect" and the "innovation compensation effect." The Porter hypothesis, proposed by Porter (1991) [12] and Porter and van der Linde (1995) [13], posits that well-designed and effectively enforced environmental regulations do not necessarily weaken firm competitiveness. Instead, they may drive firms to engage in technological innovation, improve resource efficiency, and optimize production processes, thereby generating an innovation compensation effect that partially or even fully offsets the compliance costs associated with environmental regulations. Subsequently, studies by Jaffe and Palmer (1997) [14], Acemoglu et al. (2012) [15], He et al. (2020) [16], and Colmer et al. (2025) [17], among others, conducted extensive empirical tests on whether environmental regulations can promote innovation and productivity gains. Some of these studies found that environmental regulations can stimulate R&D investment and green innovation, thereby supporting the Porter hypothesis.

Within China's institutional context, environmental policies are predominantly enforced through administrative constraints, whereas market-based incentive mechanisms remain underdeveloped. Existing research has largely examined the impact of environmental regulation on firm productivity, with a substantial body of evidence suggesting that stringent environmental policies tend to suppress Total Factor Productivity (Becker and Henderson, 2000; Gollop and Roberts, 1983; Gray, 1987) [18–20]. On the one hand, environmental regulations increase firms' compliance costs (Jensen and Meckling, 1976; Jorgenson and Wilcoxen, 1990) [21,22], forcing additional investments in pollution abatement, equipment renewal, and emission control. These expenditures crowd out resources that might otherwise be devoted to technological innovation and productivity-enhancing activities (Barbera and McConnell, 1986) [23]. On the other hand, environmental policies may generate uneven inter-industry resource flows, imposing constraints on high-pollution firms in access to finance, land, and labor. Such distortions in capital allocation efficiency ultimately depress firms' productivity (Li et al., 2016; Palmer et al., 1995) [24,25]. Furthermore, frequent or intensive policy interventions exacerbate uncertainty in the external business environment, weakening firms' investment willingness and innovation incentives, and further impeding productivity growth (Baker et al., 2016; Bloom, N., 2009; Gulen and Ion, 2015) [9,26,27].

Although a substantial body of literature has examined the relationship between environmental policies and firm productivity, the focus has largely been on traditional

policy instruments—such as regulatory stringency, pollution levies, and green credit—while institutional reforms in the governance structure of environmental agencies have received comparatively little attention. In this regard, the Vertical Management Reform of Environmental Protection Agencies, as an innovative institutional arrangement in environmental governance, is likely to constitute an important determinant of firm productivity by reshaping corporate decision-making processes and external constraints. Unlike conventional environmental policies (Wang and Chen, 2010; Zhang and Wen, 2008) [28,29], the vertical reform does not rely on decentralized local governance but instead dismantles local protectionist barriers. At its core, the reform enhances governance effectiveness through four institutional mechanisms—provincial-level centralization, direct data reporting, centralized law enforcement, and joint accountability of party and government officials. These arrangements fundamentally address the entrenched dilemma in which environmental protection has historically yielded to GDP growth. By shifting environmental governance from "technical execution" to "political accountability," the reform has significantly strengthened regulatory effectiveness. Against this backdrop, investigating how the vertical management reform of environmental protection agencies shapes firms' Total Factor Productivity through institutional design and policy enforcement not only deepens our understanding of the interaction between environmental protection and firm efficiency but also offers a theoretical foundation for improving China's national environmental governance system.

Current research on environmental policies reveals two major gaps. First, much of the existing literature focuses on the micro-operational aspects of policy—such as technological implementation and practical application—while neglecting institutional deficiencies in the governance systems of environmental agencies. This narrow perspective may account for certain partial effects of environmental policies but remains trapped in a vicious cycle of "local protectionism → data distortion → weak enforcement → diluted accountability," thereby limiting a comprehensive evaluation of policy effectiveness. Therefore, further research is needed to examine how environmental governance systems, in the context of institutional restructuring, influence economic development and firm-level efficiency. Second, the existing literature has predominantly evaluated firms through indicators such as production efficiency and resource allocation outcomes, while overlooking the social responsibilities firms ought to bear in environmental protection. Indeed, treating TFP as the sole benchmark of corporate performance yields a partial and incomplete assessment. Firms striving for efficiency gains must simultaneously integrate social responsibility and sustainable development considerations into their objectives. Neglecting this dimension risks producing biased assessments of policy effectiveness. Against this backdrop, this paper investigates the vertical management reform of environmental protection agencies and employs a multi-period difference-in-differences (DID) approach to empirically assess its impact on firms' Total Factor Productivity (TFP). In doing so, it seeks to bridge the gap at the intersection of institutional policy design, social responsibility constraints, and efficiency outcomes.

Drawing on panel data of Chinese A-share listed firms from 2012 to 2022, this study implements a multi-period difference-in-differences framework to rigorously analyze the relationship between the vertical management reform of environmental protection agencies and firms' Total Factor Productivity. The main findings can be summarized as follows. First, the reform significantly depressed firms' Total Factor Productivity in pilot regions, and this result remains robust across a battery of robustness tests. Second, the mechanism analysis reveals that the reform reduces TFP primarily by constraining technological innovation and distorting capital allocation efficiency. Third, the heterogeneity analysis demonstrates that the adverse effects are more pronounced among state-owned enterprises, firms operating under weaker regulatory scrutiny, and those located in China's eastern region. These

findings suggest that policymakers should be cautious about the short-term productivity costs of the vertical management reform. By adopting a "three-pillar" strategy of targeted buffers, innovation incentives, and precise interventions, firms can be guided to shift from "passive compliance" to "proactive upgrading," ultimately achieving a win–win outcome of strengthened environmental governance and enhanced productivity growth.

This study makes several contributions. First, from an institutional perspective, it uncovers a novel mechanism through which environmental policies affect firms' total factor productivity. By extending the analytical lens to the governance system itself, this paper systematically examines how the vertical management reform of environmental protection agencies influences firm efficiency through institutional restructuring, thereby broadening the institutional dimension of environmental policy research. Second, this paper identifies a novel mechanism whereby the vertical management reform of environmental protection agencies affects firms' TFP through technological innovation capacity and capital allocation efficiency. This finding highlights the profound impact of institutional policies on firms' internal factor operations and provides new mechanism-based evidence for understanding the transmission channels between environmental governance and firm efficiency, thereby enriching the theoretical connotation of the "regulation–innovation–efficiency" nexus. Third, this study provides new evidence on the relationship between the vertical management reform of environmental protection agencies and firm efficiency from a multidimensional heterogeneity perspective. Specifically, it examines the heterogeneous effects of environmental policies on TFP across firms, industries, and regions. This not only enriches the existing literature at the academic frontier (Brown et al., 2022) [30] but also offers valuable policy insights into reconciling environmental protection with sustained economic growth. Fourth, by combining theoretical reasoning with rigorous empirical testing, this paper confirms a novel conclusion: the vertical management reform of environmental protection agencies exerts a significantly negative effect on firms' TFP. This finding challenges the partial understandings of environmental policy effects in prior studies (Xu and Kim, 2022) [31] and provides more compelling empirical evidence for understanding the complex relationship between environmental governance institutions and firm efficiency.

The remainder of the paper is structured as follows. Section 2 introduces the policy background and theoretical framework. Section 3 describes the research design. Section 4 presents the empirical results, and Section 5 conducts the heterogeneity analysis. Section 6 concludes with the main findings and their policy implications.

## 2. Policy Background and Research Hypotheses

### *2.1. Policy Background*

How can environmental protection and economic development advance together? An important approach is to achieve a balance between environmental sustainability and economic growth through environmental protection policies. At present, the global environmental governance system exhibits an institutional evolution characterized by the coexistence of "legal rigidity" and "decentralized adaptation." In the United States, the Environmental Protection Agency (EPA) exercises vertical authority over cross-state pollution, with the Clean Air Act authorizing federal courts to impose substantial fines on non-compliant enterprises. The European Union, by contrast, has developed the Emissions Trading System (ETS), which harmonizes the allocation of carbon emission quotas and incorporates cross-border liability mechanisms to curb "free-rider" behavior (Ellerman and Buchner, 2007) [32]. Taken together, these practices indicate that successful environmental governance requires the simultaneous resolution of three core challenges: the scientific allocation of authority, the effective calibration of policy instruments, and the functioning

of credible social oversight. These international experiences provide important lessons for China's vertical management reform as it seeks to evolve from a "systemic breakthrough" to a vehicle for "efficiency enhancement."

In the context of China's transition toward high-quality development, reconciling the "dual constraints" of economic growth and ecological protection has become a central challenge for environmental governance. In 2010, the National Development and Reform Commission (NDRC) introduced the Notice on Launching Pilot Programs for Low-Carbon Provinces and Cities, which sought to explore pathways for simultaneously fostering economic development, improving livelihoods, addressing climate change, reducing carbon intensity, and advancing green growth during the country's rapid industrialization and urbanization. Between 2011 and 2014, the National Ecological Protection Red Line—Technical Guidelines for Delimiting Ecological Function Baselines (Trial) was introduced, establishing one of the most stringent ecological protection regimes in China. This framework imposed higher regulatory standards on ecological function preservation, environmental quality assurance, and the utilization of natural resources, thereby fostering a balanced relationship among population, resources, and the environment, and aligning economic, social, and ecological benefits. In 2015, the Environmental Protection Inspection Program (Trial) was approved, establishing a normalized inspection mechanism that institutionalized the principles of "joint responsibility of the Party and government" and "dual accountability for a single post," thereby providing a stable institutional foundation for routine environmental oversight. However, the traditional local government–dominated environmental governance system has long been hindered by three structural contradictions: local protectionism leading to distorted monitoring data (Bai et al., 2004; Qi and Zhang, 2014) [33,34]; administrative boundaries weakening the effectiveness of cross-regional pollution control (Wang and Zhao, 2021) [35]; and the "inverted authority–responsibility structure" of grassroot environmental agencies, resulting in weak enforcement (Lo et al., 2006) [36]. These institutional deficiencies have placed firms in a persistent dilemma between enjoying the "dividends of weak regulation" and bearing "high compliance costs," underscoring the urgent need for systemic reforms to break the vicious cycle of "pollution havens" and "efficiency losses."

To fundamentally resolve these issues, in 2016 the General Office of the CPC Central Committee and the General Office of the State Council issued the Guiding Opinions on the Pilot Reform of the Vertical Management System for Monitoring, Inspection, and Law Enforcement of Environmental Protection Agencies below the Provincial Level. This directive marked the initiation of a structural reform of China's environmental governance system. The policy mandated a reform of the foundational institutions of environmental governance by establishing a local management system that combines vertical and horizontal coordination, delineates responsibilities, strengthens accountability, and enhances authority and efficiency. It also emphasized enforcing supervisory responsibilities over local governments and their departments, thereby improving the independence, uniformity, authority, and effectiveness of environmental monitoring, inspection, and law enforcement.

According to the official guidelines, pilot provinces were instructed to experiment with locally adapted approaches, refine implementation measures, and take the lead in policy execution on a trial basis. For instance, Hebei and Chongqing were approved as the first pilot regions in 2016. In 2017, Tianjin, Shandong, Jiangsu, Jiangxi, Hubei, Fujian, and Qinghai were included, followed in 2018 by Shanghai, Guangxi, and Shaanxi. Specifically, the reform was built on two pillars: the provincial-level unification of monitoring authority and enforcement authority, which effectively severed the chain of local interference. By abolishing the enforcement functions of county-level environmental bureaus and establishing cross-regional enforcement branches, the reform eliminated the room

for local protectionism in "data manipulation → discretionary punishment." At the same time, a provincial-level environmental inspection system was established, imposing strict accountability on municipal officials under the principles of "joint Party–government responsibility" and "lifetime accountability." By the end of 2018, the vertical management reform pilots had been extended to 13 provinces across China, marking an institutional transition from "baseline defense" to "systematic governance." The reform not only redefined the logic of power distribution between the central and local governments in environmental affairs, but also placed unprecedented compliance pressure on firms through standardized enforcement and centralized monitoring. This institutional transformation thus provides an ideal quasi-experimental setting for examining the interaction between institutional rigidity and microeconomic efficiency. Figure 1 illustrates the spatial distribution of pilot cities under the vertical management reform of environmental protection agencies in 2018, generated using ArcGIS 10.8 software.

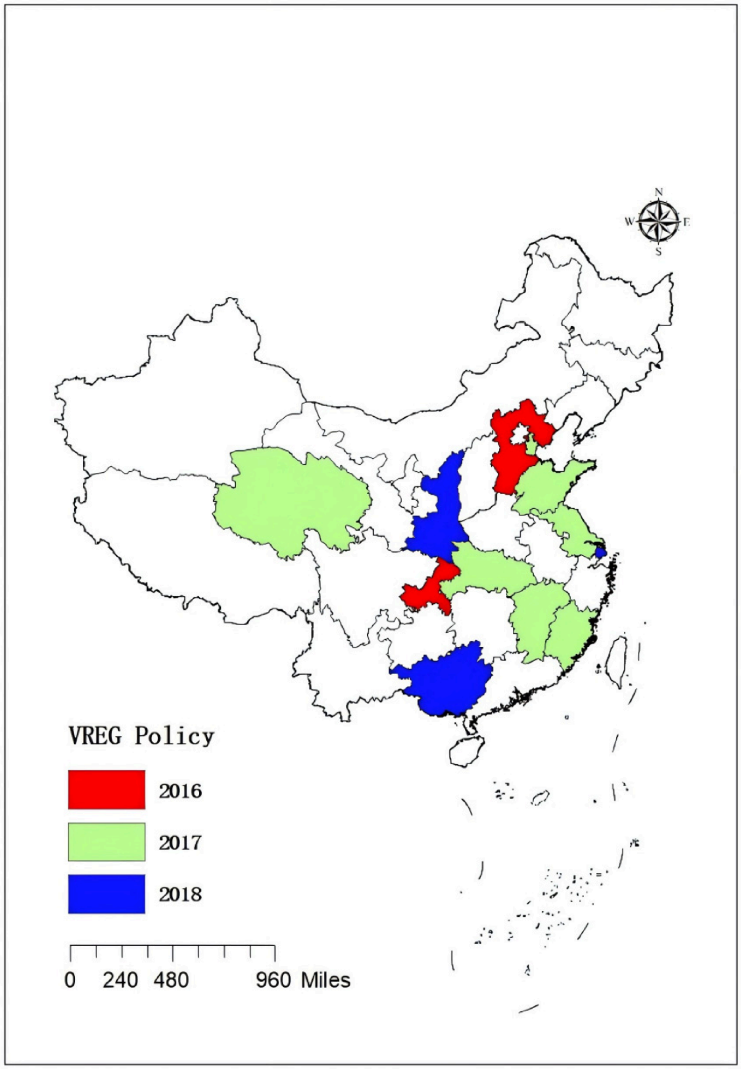



**Figure 1.** Spatial distribution of pilot cities implementing the vertical management reform of environmental protection agencies in 2018.

### *2.2. Research Hypothesis*

The reform of vertical management of environmental protection agencies differs significantly from traditional environmental regulation policies. First, the nature of the policies differs. Traditional environmental regulation policies primarily target corporate pollu-

tion emissions directly through measures such as raising emission standards, increasing penalties for pollution, imposing pollution discharge fees, or implementing green finance constraints, whereas the core of the reform of vertical management of environmental protection agencies lies in adjusting the power structure of environmental governance and the administrative enforcement system. Second, the targets of these policies differ. Traditional environmental regulations primarily constrain corporate pollution emissions and production activities, whereas the vertical management reform primarily affects the relationship between local governments and environmental protection departments regarding authority and responsibility. By reducing local protectionism and administrative intervention, it indirectly alters the regulatory environment faced by enterprises. Third, the enforcement mechanisms differ. During local implementation, traditional environmental policies may be influenced by local economic growth targets and fiscal incentives, leading to issues such as selective enforcement, weakened oversight, and data distortion. In contrast, the vertical management reform enhances the independence, uniformity, and credibility of environmental oversight by centralizing monitoring, inspection, and enforcement authorities, strengthening provincial-level coordination, and reinforcing accountability mechanisms. Fourth, corporate expectations differ. Under traditional environmental regulations, enterprises may have formed low compliance expectations based on local protectionism or enforcement flexibility; following the vertical management reform, the rigidity and predictability of regulatory enforcement have increased, leading to a corresponding rise in the compliance pressures and governance costs faced by enterprises.

Therefore, the theoretical significance of the reform of the vertical management system for environmental protection agencies does not lie in simply strengthening the intensity of environmental regulation, but rather in transforming the logic of regulatory enforcement by reshaping the structure of environmental governance. This institutional reform shifts environmental regulation from a decentralized enforcement model dominated by local governments to a more independent and unified vertical governance model, which may have an impact on corporate resource allocation, technological innovation, and production efficiency that differs from that of general environmental regulatory policies.

#### 2.2.1. Vertical Environmental Management and Firm-Level Total Factor Productivity

Firms' Total Factor Productivity is shaped not only by their capacity for technological innovation (Bloom and Van Reenen, 2007; Comin and Hobijn, 2010) [37,38], but also by the efficiency with which capital is allocated (Brandt et al., 2012; Hsieh and Klenow, 2009) [39,40]. As a key policy representing China's current environmental governance system, the vertical management reform of environmental protection agencies has substantially constrained the development of firms' TFP through several channels. First, according to transaction cost theory in new institutional economics, institutional arrangements directly influence the level of transaction costs in economic activities, thereby affecting resource allocation efficiency and economic performance (North, 1990; Williamson, 1985) [41,42]. The vertical management reform enhances the authority and enforcement capacity of the central government in environmental governance, thereby increasing firms' transaction costs of compliance. Stricter, more independent, and more frequent environmental supervision compels firms to allocate greater resources to information disclosure, investment in pollution-control facilities, compliance reporting, and engagement with regulators (Eccles et al., 2014; Krueger et al., 2024; Shapiro and Walker, 2018; Walker, 2013) [43–46]. These compliance-related expenditures crowd out resources that could otherwise be allocated to R&D and production expansion, thereby exerting a direct suppressive effect on firms' TFP. Second, drawing on resource constraint theory, firms' resources—including financial and human capital—are inherently limited (Kornai, 1979) [47]. The vertical management

reform compels firms to divert resources away from productivity-enhancing activities toward environmental compliance, generating a crowding-out effect that undermines their ability to improve efficiency and foster innovation (Zhao and Sun, 2016) [48]. This dynamic leads to stagnation, or even regression, in the growth of Total Factor Productivity. Finally, drawing on principal–agent theory, multi-level governance structures are characterized by goal divergence and information asymmetry between higher- and lower-level governments (Jensen and Meckling, 1976; Ross, 1973) [21,49]. Local governments, driven by incentives for GDP growth and fiscal revenues, often protect heavily polluting firms, thereby rendering environmental regulations "soft constraints" (Mertha, 2005; Tian et al., 2022) [50,51]. The vertical management reform was introduced precisely against this backdrop, reinforcing central oversight of local environmental governance and tightening enforcement constraints. Consequently, firms are compelled to increase investments in environmental compliance to satisfy stricter regulatory requirements. This raises compliance costs and managerial burdens, further crowding out resources that could otherwise be devoted to productivity enhancement, thereby reducing TFP (Zhong et al., 2021) [52]. Based on the foregoing analysis, we formulate the following hypothesis:

**H1.** *The vertical management reform of environmental protection agencies significantly suppresses the development of firms' total factor productivity.*

#### 2.2.2. Analysis of Underlying Mechanisms

The vertical management reform of environmental protection agencies reduces firms' Total Factor Productivity primarily through two channels: by weakening their technological innovation capacity and by distorting the efficiency of capital allocation. A decline in innovation capacity is manifested in diminished expenditures on research and development (R&D) as well as reduced investment in technological upgrading. First, compliance cost theory posits that environmental regulation increases firms' costs, thereby imposing new constraints on their production decisions (Jaffe et al., 1995; Ryan, 2012) [53,54]. Consequently, firms are compelled to reallocate R&D expenditures toward environmental compliance, and this reduction in innovation investment inevitably hampers technological progress (Liu et al., 2024) [7], ultimately reducing TFP. Second, real options theory argues that firms incorporate assessments of external environmental risks into their decision-making when undertaking innovation investments (Trigeorgis and Reuer, 2017; Verdu et al., 2012) [55,56]. Following the vertical reform, the heightened unpredictability of environmental regulation substantially amplified firms' operational risks. As a result, managers became more inclined to eschew long-term innovation projects with uncertain returns, opting instead for conservative business strategies (Shao and Xu, 2025) [57]. Such underinvestment in innovation critically weakened firms' technological capabilities and, in turn, curtailed the growth of TFP. Finally, the stricter environmental regulations introduced by the reform may overly direct firms to channel their limited innovation resources into technologies aimed solely at meeting specific regulatory standards, rather than into core production technologies that enhance process efficiency, reduce costs, or create new markets. This "narrowing" or "deviation" in innovation trajectories may facilitate regulatory compliance but is unlikely to generate substantive improvements in overall productivity or strengthen firms' market competitiveness (Ambec et al., 2013) [58]. Building on the above analysis, we advance the following hypothesis:

**H2.** *The vertical management reform of environmental protection agencies lowers firms' Total Factor Productivity by weakening their technological innovation capacity.*

Investment distortions and financing frictions constitute the fundamental causes of low resource allocation efficiency. First, according to resource misallocation theory, external interventions—such as targeted policies or regulatory constraints—can distort firms' investment decisions (Child and Yuan, 1996; Gulen and Ion, 2015) [27,59], thereby impeding the flow of capital to its most productive uses and resulting in systematic resource misallocation (Hu et al., 2023) [60]. As a stricter and more centralized form of environmental regulation, the vertical reform may compel firms to invest in abatement facilities beyond their actual emission-reduction needs or economically optimal scale. This results in an excessive allocation of capital to low-productive or even non-productive environmental assets, and such distortions in capital allocation severely hinder the growth of firms' Total Factor Productivity. Furthermore, financing constraint theory suggests that external frictions in capital markets restrict firms' access to funds, thereby impairing optimal investment decisions (Abdeljawad et al., 2024; Fazzari et al., 1987) [61,62]. On the one hand, the additional environmental expenditures required by the vertical reform drain firms' internal cash flows, thereby weakening their capacity for self-financing. At the same time, the immobilization of substantial capital in highly specific environmental assets reduces the share of high-quality assets available as collateral for external financing. On the other hand, heightened compliance risks under stricter regulation are often interpreted by financial institutions as elevated operational risk, thereby raising firms' financing costs or restricting their access to external credit (Ma and Hu, 2024) [63]. These financing frictions further distort capital allocation, impeding the flow of capital to its most productive uses. Building on the above theoretical framework, we advance the following hypothesis:

**H3.** *The vertical management reform of environmental protection agencies suppresses firms' Total Factor Productivity by distorting the efficiency of capital allocation.*

## 3. Research Design

### *3.1. Sample Construction and Data Sources*

This study uses A-share-listed firms in Shanghai and Shenzhen from 2012 to 2022 as the research sample and applies the following screening and processing steps: (i) financial firms are excluded; (ii) firms with special treatment (ST, *ST, and PT) designations are removed; (iii) firms with missing values for key variables are excluded; and (iv) to mitigate the influence of outliers, all continuous variables are winsorized at the 1% level on both tails. The implementation dates of the vertical management reform of environmental protection agencies in different provinces are obtained from official releases by the Ministry of Ecology and Environment of the People's Republic of China and the websites of provincial environmental bureaus, supplemented by manual collection and verification from related reports. Firm-level and regional-level data are mainly drawn from the China Stock Market & Accounting Research (CSMAR) database and the China Research Data Service Platform (CNRDS). In addition, regional-level data is matched based on the location of the listed companies. Specifically, city-level variables are matched according to the city where the listed company is located, and provincial-level variables are matched according to the province where the listed company is located, thereby forming a panel data structure at the firm–city–province–year level.

### *3.2. Model Specification*

To examine the relationship between the vertical management reform of environmental protection agencies and firms' total factor productivity (TFP), the following model is specified:

$$TFP_{i,t} = \alpha + \beta VMR - EPA_{s,t} + \gamma X_{i,t} + \delta_t + \varphi_i + \varepsilon_{i,t} \quad (1)$$

where $TFP_{i,t}$ denotes the total factor productivity of firm $i$ in year $t$, which is measured using both the OP and LP methods. $VMR\text{-}EPA_{s,t}$ is a dummy variable indicating whether province $s$ implemented the vertical management reform of environmental protection agencies in year $t$. $X_{i,t}$, t represents a set of control variables at the firm, city, and provincial levels. $\delta_t$ and $\varphi_i$ denote year and firm fixed effects, respectively, and $\varepsilon_{i,t}$ is the error term. The coefficient of interest is $\beta$. If $\beta$ is significantly negative, it implies that the vertical management reform of environmental protection agencies significantly suppresses firms' TFP, thereby supporting Hypothesis 1.

### *3.3. Variable Definitions*

#### 3.3.1. Explained Variable: Measurement of Total Factor Productivity

To date, the main approaches for estimating firms' TFP are the semi-parametric method proposed by (Olley and Pakes, 1992) [64] (OP method) and the semi-parametric method proposed by (Levinsohn and Petrin, 2003) [65] (LP method). Since the OP method is more effective in addressing simultaneity bias and sample selection bias, this paper estimates TFP based on the OP framework using the following model:

$$\begin{aligned} lnY_{i,t} = \beta_0 + \beta_k lnK_{i,t} + \beta_l lnL_{i,t} + \beta_a age_{i,t} + \beta_s State_{i,t} + \beta_e EX_{i,t} + \sum_m \delta_m year_m \\ + \sum_n \lambda_n prov_n + \sum_k \xi_k ind_k + \varepsilon_{i,t} \end{aligned} \quad (2)$$

In the model, $Y_{i,t}$ denotes operating revenue; $K_{i,t}$ represents capital input, measured by the net value of fixed assets; $L_{i,t}$ denotes labor input, measured by the number of employees; *age* refers to the firm's age; *State* is a dummy variable indicating whether the firm is state-owned (equal to 1 if state-owned, 0 otherwise); *EX* is a dummy variable indicating whether the firm engages in exports; *year*, *prov*, and *ind* represent time, province, and industry fixed effects, respectively; and $\varepsilon_{i,t}$ is the error term. Among these variables, the state variables (state) include *lnK* and *age*; the control variables (cvars) include *state* and *EX*; the proxy variable (proxy) is the firm's investment *lnL*, measured by cash payments for the purchase and construction of fixed assets, intangible assets, and other long-term assets; other variables such as *year*, *prov*, and *ind* are classified as free variables (free); and the *exit* variable (exit) is generated based on the firm's survival and operational status.

#### 3.3.2. Explanatory Variable: VMR-EPA

To construct the core explanatory variable, this paper identifies whether and when each province implemented the vertical management reform of environmental protection agencies by searching the official websites of provincial environmental protection bureaus using keywords such as "province name + vertical management reform of environmental protection agencies" and "location name + vertical management reform of monitoring, inspection, and enforcement agencies." Specifically, if province $s$ had implemented the reform in year $t$, the variable *VMR-EPA* is assigned a value of 1; otherwise, it is 0.

#### 3.3.3. Control Variables

To mitigate potential estimation bias arising from omitted variables, this paper incorporates a series of firm-level control variables, including firm size (*Size*), firm age (*Age*), capital intensity (*K*), ownership type (*Soe*), return on equity (*Roe*), and leverage ratio (*Lev*). Considering that firms' total factor productivity may also be closely related to the level of local economic development, this study further includes city-level and province-level control variables: city-level GDP per capita (*Cgdp*) and province-level GDP per capita (*Pgdp*).

Table 1 reports the detailed definitions of all variables used in this study.

**Table 1.** Variable Definitions.

| Variable Type | Variable | Abbreviation | Definition | Data Level |
|---|---|---|---|---|
| Dependent Variable | Total Factor Productivity | TFP-OP | Firm-level Total Factor Productivity Estimated by the Olley–Pakes Method | Firm |
| | | TFP-LP | Firm-level Total Factor Productivity Estimated by the Levinsohn–Petrin Method | |
| Independent Variable | Environmental Vertical Management System | VMR-EPA | The variable equals 1 if the region has implemented the vertical management reform of environmental protection agencies, and 0 otherwise. | Province |
| Control Variables | Firm Size | Size | Natural logarithm of total assets | Firm |
| | Firm Age | Age | Years Since Listing | Firm |
| | Capital Intensity | K | Net Fixed Assets/Total Assets | Firm |
| | Ownership Type | Soe | SOE Dummy, which equals 1 if the firm is a state-owned enterprise (SOE), and 0 otherwise | Firm |
| | Return on Equity | Roe | Net Profit/Shareholders' Equity | Firm |
| | Leverage | Lev | Total liabilities/total assets (year-end) | Firm |
| | City-level GDP per Capita | Cgdp | The Natural Logarithm of City-level GDP per Capita | City |
| | Province-level GDP per Capita | Pgdp | The Natural Logarithm of Province-level GDP per Capita | Province |
| Mechanism Analysis | Technological Innovation Capability | RD | R&D Investment/Net Fixed Assets | Firm |
| | Capital Allocation Efficiency | Invest | Net Cash Paid for the Acquisition of Fixed Assets, Intangible Assets, and Other Long-term Assets Minus Cash Received from the Disposal of Such Assets, Scaled by Total Assets | Firm |
| | Tobin's Q | Q | Market Value of Firm/Replacement Cost of Assets | Firm |

### *3.4. Explanation of Assumptions Regarding the Selection and Identification of Policy Pilots*

As a reform of the environmental governance system that is centrally planned and implemented in phases at the local level, the pilot provinces for the vertical management reform of environmental protection agencies were not selected at random in the strictest sense. The first and subsequent pilot regions typically face significant environmental governance pressures, high levels of industrial pollution exposure, a certain foundation for administrative reform, and regional representativeness. Therefore, when viewed solely at the provincial level, pilot regions and non-pilot regions may exhibit certain differences in

terms of economic development, industrial structure, and the foundation for environmental governance. This paper does not treat this policy pilot as a fully randomized experiment, but rather interprets it as an institutional shock with quasi-natural experiment characteristics. On the one hand, the pilot arrangements were primarily advanced in a unified manner by central and provincial governments based on the objectives of environmental governance reform; individual micro-enterprises had little direct influence over whether or when their region would be included in the pilot program. Consequently, this institutional change exhibits strong exogeneity with respect to changes in firm-level productivity. On the other hand, this paper mitigates the impact of selection bias on the estimation results as much as possible through the use of firm fixed effects, year fixed effects, and control variables at both the firm and regional levels.

Furthermore, to account for the fact that the pilot provinces were not selected strictly at random and to ensure the feasibility of the difference-in-differences method, it is important to note that the key identification premise of this method does not require the treatment and control groups to be completely identical in all characteristics prior to policy implementation. Instead, it requires that the two groups exhibit similar trends in their characteristics prior to the policy shock. Therefore, to further examine whether systematic trend differences existed between the treatment and control groups prior to policy implementation, this study retains only pre-policy implementation samples and constructs an interaction term between the treatment group dummy variable and the time trend term for testing. If this interaction term is significant, it indicates that the treatment and control groups already exhibited different trends prior to policy implementation; conversely, it suggests that no significant pre-policy trend differences existed between the two groups.

Table 2 reports the results of the trend difference test prior to policy implementation. In Column (1), where firm-level total factor productivity (TFP) estimated using the OP method is the dependent variable, the estimated coefficient of the interaction term (Trend-Tread) is −0.0173 and is not statistically significant; in Column (2), where firm-level TFP estimated using the LP method is the dependent variable, the estimated coefficient of the interaction term (Trend-Tread) is 0.0012 and is also not statistically significant. This indicates that, prior to the formal implementation of the policy, there were no significant systematic differences in the trends of total factor productivity between firms in the treatment group and those in the control group. In other words, although the pilot regions for the vertical management reform of environmental protection agencies were not selected entirely at random, the treatment and control groups exhibited similar trends in productivity changes before the policy took effect, thereby providing empirical support for the use of the difference-in-differences method to identify policy effects in this study.

**Table 2.** Test for Pre-Treatment Trends Between the Treatment Group and the Control Group.

| | **(1)**<br>**TFP-OP** | **(2)**<br>**TFP-LP** |
|---|---|---|
| Trend-tread | −0.0173 | 0.0012 |
| | (−1.24) | (0.08) |
| Size | 0.2916 *** | 0.4527 *** |
| | (5.52) | (9.10) |
| K | −0.4767 *** | −0.6657 *** |
| | (−3.90) | (−5.83) |
| Soe | 0.0527 | 0.0297 |
| | (0.34) | (0.35) |

**Table 2.** *Cont.*

| | (1) TFP-OP | (2) TFP-LP |
|---|---|---|
| Roe | 0.9449 *** | 0.9764 *** |
| | (5.96) | (6.34) |
| Lev | 0.3372 ** | 0.3876 *** |
| | (2.42) | (2.78) |
| Cgdp | −0.0518 | −0.0415 |
| | (−0.72) | (−0.61) |
| Pgdp | 0.2973 | 0.3524 |
| | (1.01) | (1.29) |
| -cons | −2.7250 | −5.0710 |
| | (−0.81) | (−1.60) |
| Year | Yes | Yes |
| Stkcd | Yes | Yes |
| N | 2519 | 2519 |
| $R^2$ | 0.9410 | 0.9630 |

*t* statistics in parentheses. ** $p < 0.05$, *** $p < 0.01$.

## 4. Empirical Analysis

### *4.1. Benchmark Regression Analysis*

Table 3 presents the baseline regression results on the impact of the Vertical Management Reform of Environmental Protection Agencies (VMR-EPA) on firms' Total Factor Productivity. The dependent variable is TFP, estimated using the Olley–Pakes (OP) method. All specifications include firm and year fixed effects, and standard errors are clustered at the firm level to account for potential heteroskedasticity and serial correlation. Column (1) of Table 3 reports the regression results without any control variables, Column (2) presents the results after including firm-level controls, and Column (3) shows the results with all levels of control variables included. The results indicate that, without any control variables, the estimated coefficient of the VMR-EPA policy is −0.0550, significant at the 1% level, implying that firms in pilot provinces exhibit 5.50% lower TFP than those in the control group. This negative effect remains robust after the inclusion of additional controls. With the full set of control variables in Column (3), the estimated impact is −0.0426, suggesting that firms in pilot provinces experienced a 4.26% decline in TFP following the implementation of the VMR-EPA policy relative to the control group. Overall, the baseline regression results confirm that the VMR-EPA policy significantly reduces firms' Total Factor Productivity, thereby lending support to Hypothesis 1.

Regarding the control variables, the coefficient on Size is significantly positive at the 1% level, indicating that larger firms achieve higher TFP. This result is consistent with the view that larger firms benefit from economies of scale, stronger access to finance, higher-quality human capital, and more sophisticated management systems (Bai et al., 1997) [66]. The coefficient on Age is likewise significantly positive at the 1% level, suggesting that firms accumulate technological experience and organizational knowledge through prolonged production activities, which gradually enhance resource allocation efficiency. Moreover, firms with longer survival horizons tend to sustain more stable supply chains, customer relationships, and governance structures, and such institutional stability may ultimately translate into productivity advantages (Teece, 2007) [67]. By contrast, the coefficient on capital intensity (K) is −0.5366 and statistically significant at the 1% level, indicating that firms with a higher share of capital input exhibit lower TFP. This finding suggests that many capital-intensive firms face challenges such as inefficient investment, misallocation of resources, and weak adaptability to environmental regulation, which hinder their ability

to realize technological progress and production optimization under tightening policy constraints. As a result, improvements in Total Factor Productivity are substantially constrained. With respect to financial indicators, the coefficients on ROE and Leverage (Lev) are both positive and significant at the 1% level, indicating that firms with stronger profitability and more abundant cash flows exhibit higher TFP. Furthermore, higher leverage expands firms' access to external financing, mitigates financing constraints, and facilitates investment in high-return R&D projects or advanced production equipment (Margaritis and Psillaki, 2007) [68]. Thus, leverage exerts a significantly positive effect on firms' TFP. Finally, the coefficients on city-level GDP per capita (Cgdp) and province-level GDP per capita (Pgdp) are negative and statistically significant at the 5% and 10% levels, respectively. A plausible explanation is that in more developed regions, substantially higher land and labor costs crowd out firms' R&D investments, thereby constraining innovation and reducing TFP (Ning et al., 2016) [69].

**Table 3.** Baseline Regression Results.

| | (1)<br>TFP-OP | (2)<br>TFP-OP | (3)<br>TFP-OP |
|---|---|---|---|
| VMR-EPA | −0.0550 *** | −0.0445 *** | −0.0426 *** |
| | (−5.18) | (−4.29) | (−4.59) |
| Size | | 0.3311 *** | 0.3317 *** |
| | | (28.33) | (28.32) |
| Age | | 0.0811 *** | 0.0846 *** |
| | | (2.61) | (2.75) |
| K | | −0.5340 *** | −0.5366 *** |
| | | (−10.94) | (−11.00) |
| Soe | | 0.0308 | 0.0298 |
| | | (1.41) | (1.37) |
| Roe | | 1.0374 *** | 1.0360 *** |
| | | (24.86) | (24.83) |
| Lev | | 0.3896 *** | 0.3910 *** |
| | | (10.52) | (10.55) |
| Cgdp | | | −0.0040 ** |
| | | | (−2.36) |
| Pgdp | | | −0.0554 * |
| | | | (−1.68) |
| -cons | 6.8203 *** | −1.9697 *** | −1.3713 ** |
| | (1985.73) | (−3.86) | (−2.28) |
| Year | Yes | Yes | Yes |
| Stkcd | Yes | Yes | Yes |
| N | 13,332 | 13,332 | 13,332 |
| $R^2$ | 0.8812 | 0.9103 | 0.9103 |

*t* statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

### *4.2. Parallel Trend Test*

A key requirement for using the DID method in policy evaluation is compliance with the parallel trend assumption. Specifically, prior to the policy implementation, the treatment and control groups should exhibit similar trends without systematic differences. After the policy implementation, however, the two groups are expected to display significantly different trends. Following the existing literature (Callaway and Sant'Anna, 2021; Guo and Zhong, 2022; Li et al., 2016) [24,70,71], we employ an event study approach to analyze the effects before and after the reform.

$$TFP_{i,t} = \alpha + \sum_{\tau=-M}^{N} \theta_t Policy_{i,\tau-t} + \beta X_{i,t} + \delta_t + \varphi_i + \varepsilon_{i,t} \quad (3)$$

In Equation (3), $i$ denotes the firm and $t$ denotes time. $Policy_{i,\tau-t}$ is a dummy variable that equals 1 if firm $i$ is affected by the VMR-EPA in period $\tau$-$t$ and 0 otherwise. $\theta_t$ represents the set of coefficients capturing the impact of the *VMR-EPA* on firms' total factor productivity (TFP) in different periods. $M$ and $N$ indicate the number of periods before and after the implementation of the VMR-EPA policy, respectively. All other settings are the same as in Equation (1). To avoid multicollinearity, the year prior to the policy implementation is omitted from the regression equation. If the coefficients in the pre-treatment periods (M) are statistically insignificant, the parallel trend assumption is satisfied. As illustrated in Figure 2, prior to the implementation of the VMR-EPA policy, the estimated coefficients fluctuate around zero and show no statistical significance, indicating that the treatment and control groups exhibited comparable trends. In contrast, following the policy implementation, the coefficients decline sharply and become statistically significant, demonstrating that the VMR-EPA policy imposes a substantial negative impact on firms' Total Factor Productivity.

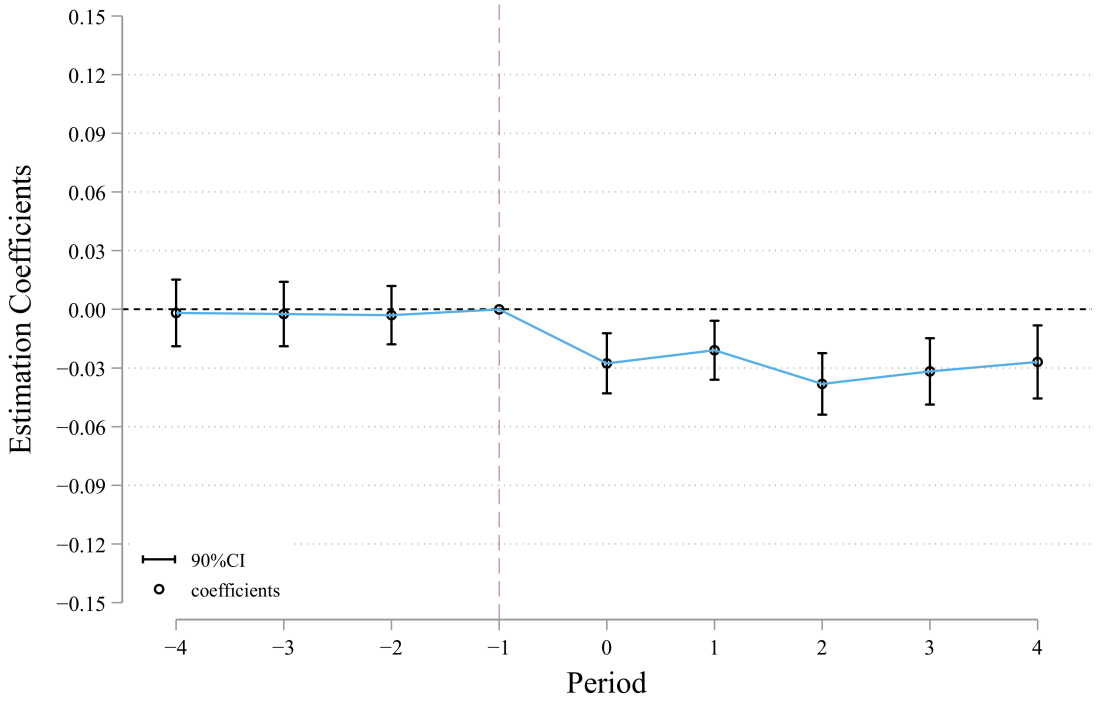
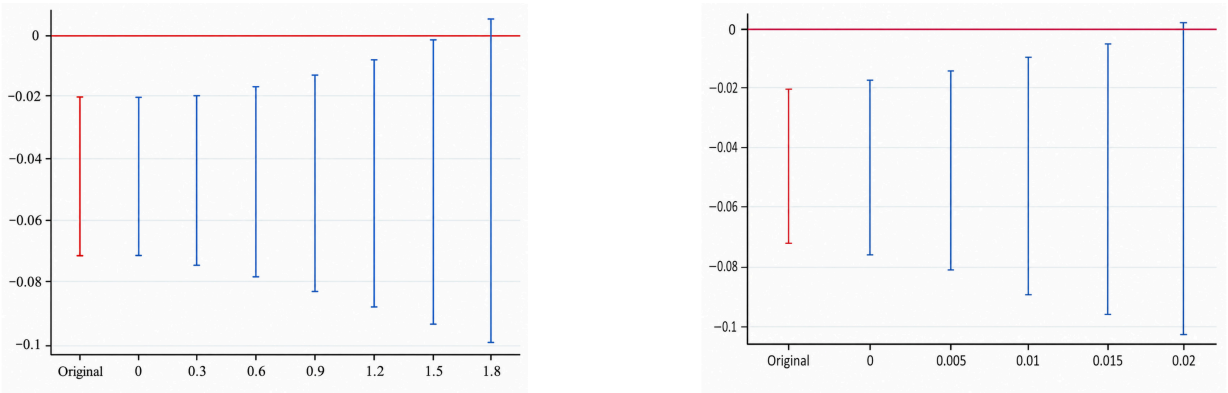



**Figure 2.** Parallel-Trends Test Results.

However, the recent literature on DID methodology suggests that pre-trend tests cannot serve as valid empirical evidence for the parallel trend assumption. (Roth et al., 2023) [72] argue that Traditional pre-trend tests lack statistical power and may lead to biased or distorted estimates and inferences. To address this limitation, Roth (2023) [72] propose a methodological framework for assessing the reliability of direct effect (DID) estimators when the parallel trends assumption may be violated. The core idea is to use the confidence intervals of post-treatment estimators for inference and sensitivity analysis. The framework consists of two steps: first, setting a maximum allowable deviation (M) to quantify the extent of potential trend misalignment; second, calculating adjusted post-treatment confidence intervals subject to this deviation threshold. If, under the maximum deviation scenario, the confidence interval for the post-treatment point estimate does not

include zero, this indicates that the estimated treatment effect is robust to potential bias arising from the violation of the parallel trends assumption.

Following (Biasi and Sarsons, 2021) [73], and their deviation-from-parallel-trends hypothesis testing method used after the implementation of pilot policies, this paper sets the maximum deviation limit (M) to one standard error to examine the sensitivity of the treatment effect to deviations from the parallel-trends hypothesis. Figure 3 reports the results of sensitivity analyses under relative deviation and smoothing constraints. Under the relative deviation constraint, the impact of the vertical management reform of environmental protection agencies (VMR-EPA) on firms' total factor productivity (TFP) in the year of policy implementation remains statistically significant, indicating strong robustness of the estimation results. Under the smoothing constraint, when a 15% deviation in the pre-treatment trend is allowed, the estimated effect in the year of policy implementation remains robust. Overall, even when a reasonable degree of deviation from the parallel trend assumption is permitted, the reform of the vertical management system of environmental protection agencies still exerts a significant negative impact on firms' total factor productivity. The above analysis not only enhances the credibility of the empirical results in this paper but also provides a more flexible identification framework for evaluating the effects of complex policy interventions.




(**a**) Relative-Deviation Constraint (**b**) Smoothness Constraint

**Figure 3.** Sensitivity Test of Parallel-Trends for Policy Implementation Effects (Note: This figure illustrates how the confidence intervals of the treatment effect vary with different levels of deviation under the relative deviation constraint (Panel (**a**)) and the smoothness constraint (Panel (**b**)). The horizontal axis (M) represents the maximum allowable deviation from the parallel trend, while the vertical axis shows the point estimates of the treatment effect along with their 90% confidence intervals. If the confidence intervals exclude zero across all deviation levels, it indicates that the treatment effect is robust to deviations from the parallel trend assumption.).

### *4.3. Robustness Test*

#### 4.3.1. Placebo Test

Considering that the core explanatory variable may be influenced by unobservable factors, this study follows the approach of (Li et al., 2016) [24] to assess their potential impact on the estimation results. The placebo test, also referred to as the pseudo-treatment test, is essentially a randomized trial (Cantoni et al., 2017; Chetty et al., 2009; Lyu et al., 2024) [74–76]. In practice, we reconstruct the treatment variable by randomly assigning the policy shock and treated firms. This random assignment is repeated 700 times to generate the empirical distribution of the estimated coefficients.

Figure 4 presents the results of the placebo test. On the vertical axis, 0.1 denotes the 10% significance level, and on the horizontal axis, −0.0426 represents the coefficient of the "actual treatment group." First, the estimated coefficients of the "pseudo-treatment groups" are mostly concentrated within the range of −0.037 to 0.037, with almost all *p*-values greater than 0.1. Second, the coefficient of the "actual treatment group" is −0.0426, which lies significantly outside the (−0.037, 0.037) interval. These differences between the "actual treatment group" and the "pseudo-treatment groups" indicate that the baseline results are not subject to substantial bias.

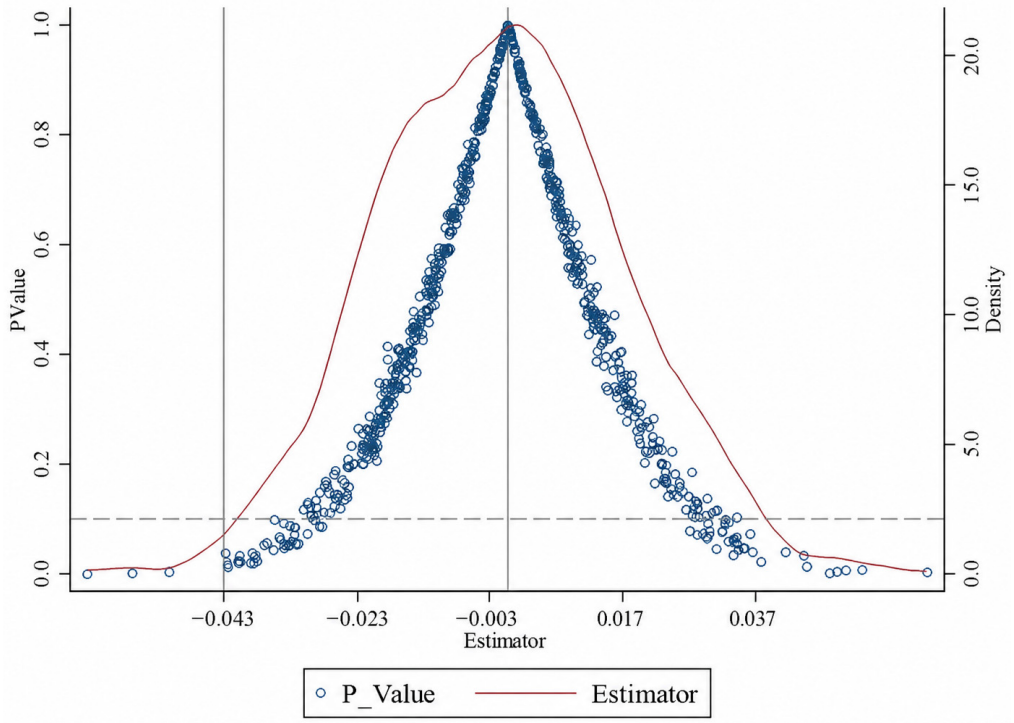



**Figure 4.** Placebo Test Results.

4.3.2. Bacon Decomposition

The Bacon decomposition breaks down the overall estimate of the multi-period DID model into a weighted average of all possible two-group comparisons, thereby revealing which cohort-to-control contrasts contribute most to the overall effect (Goodman-Bacon, 2021) [77]. In Figure 5, the horizontal axis represents the weight of each comparison, while the vertical axis shows the corresponding DID estimates. The "×" markers (earlier-treated group vs. later-control group) and "×" markers (later-treated group vs. earlier-control group) capture cross-cohort comparisons between early and late adopters of the pilot reform. The "▲" marker (treated group vs. never-treated group) indicates comparisons between pilot cities and those that never adopted the reform. The dashed line at approximately −0.05 represents the weighted average of subgroup estimates. Notably, the comparison between the treated group and the never-treated group carries the largest weight and exhibits the most significant negative estimate. This suggests that the overall negative effect is primarily driven by contrasts with cities that never became pilots. Although other comparisons carry smaller weights, most of them also yield negative estimates. This further reinforces the finding that the vertical management reform of environmental protection agencies suppresses the development of firms' total factor productivity.

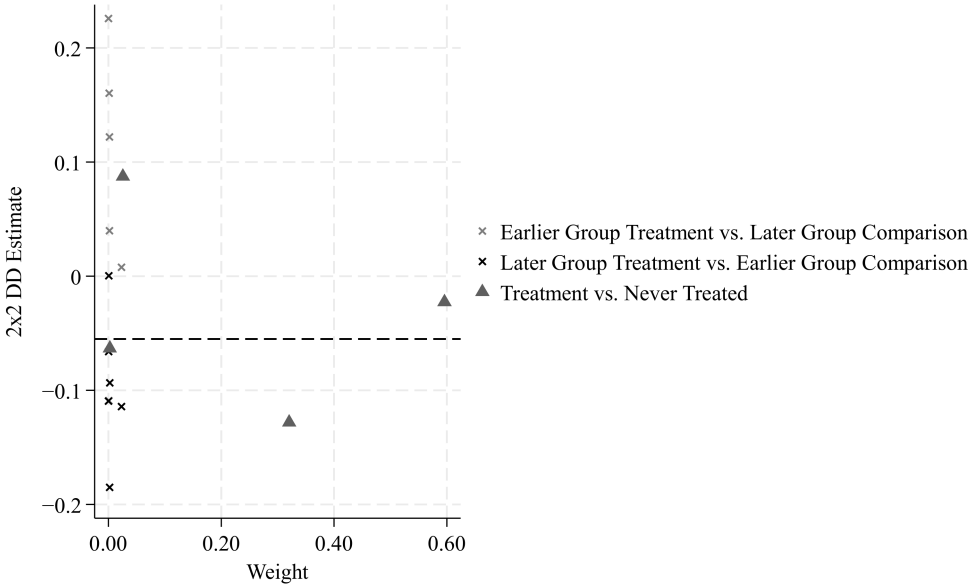



**Figure 5.** Bacon Decomposition Results.

#### 4.3.3. PSM-DID

To further test the robustness of the estimation results, we combine propensity score matching (PSM) with the multi-period DID framework, which allows us to control for baseline differences between the treatment and control groups while enhancing the credibility of the estimated policy effect. Following the existing literature (Bernard et al., 2011; Dehejia and Wahba, 2002; Rosenbaum and Rubin, 1985) [78–80], this study selected eight firm-level and regional-level covariates as matching variables and employed a one-to-one nearest-neighbor matching method with a radius of 0.05 to match the samples. Figure 6 reports the standardized deviations of each covariate before and after matching, where solid dots (•) and crosses (×) represent the standardized deviations before and after matching, respectively. The results show that the standardized deviations of all covariates fall within the ±5% range after matching, indicating good covariate balance between the treatment and control groups. After excluding unmatched samples, we re-estimated the multi-period difference-in-differences model, with the results shown in Column (1) of Table 4. The estimated coefficient for the VMR-EPA variable is −0.0356 and is statistically significant at the 10% level. These results indicate that even after controlling for sample selection bias, the reform of the vertical management system for environmental protection agencies still inhibits the growth of firms' total factor productivity.

**Table 4.** Robustness Test Results 1.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | PSM-DID | Replacing the Measurement of the Dependent Variable | The Explanatory Variable Lagged by One Period | Changing the Sample Period | | Excluding the Influence of Other Concurrent Policies | |
| | TFP-OP | TFP-LP | TFP-OP | TFP-OP | TFP-LP | TFP-OP | TFP-OP |
| VMR-EPA | −0.0356 * | −0.0353 *** | | −0.30413 *** | −0.0365 ** | −0.0428 *** | −0.0456 *** |
| | (−1.76) | (−3.69) | | (−3.40) | (−3.15) | (−4.61) | (−4.59) |
| VMR-EPAt-1 | | | −0.0312 *** | | | | |
| | | | (−3.25) | | | | |
| LCCP | | | | | | −0.0803 | |
| | | | | | | (−0.86) | |

**Table 4.** *Cont.*

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | PSM-DID | Replacing the Measurement of the Dependent Variable | The Explanatory Variable Lagged by One Period | Changing the Sample Period | | Excluding the Influence of Other Concurrent Policies | |
| | TFP-OP | TFP-LP | TFP-OP | TFP-OP | TFP-LP | TFP-OP | TFP-OP |
| EDCRP | | | | | | | 0.0125 |
| | | | | | | | (0.89) |
| Size | 0.3187 *** | 0.5067 *** | 0.3263 *** | 0.3377 *** | 0.5114 *** | 0.3320 *** | 0.3317 *** |
| | (13.37) | (46.62) | (24.76) | (22.33) | (36.71) | (28.27) | (28.33) |
| Age | 0.0803 | 0.0723 ** | 0.0766 ** | 0.1020 ** | 0.0971 ** | 0.0839 *** | 0.0840 *** |
| | (1.53) | (2.50) | (2.56) | (2.47) | (2.42) | (2.72) | (2.73) |
| K | −0.5524 *** | −0.7618 *** | −0.5846 *** | −0.5328 *** | −0.7636 *** | −0.5357 *** | −0.5376 *** |
| | (−4.48) | (−16.22) | (−10.46) | (−9.13) | (−13.61) | (−10.99) | (−11.03) |
| Soe | 0.0337 | 0.0436 ** | 0.0298 | 0.0443 | 0.0449 | 0.0290 | 0.0296 |
| | (0.77) | (2.06) | (1.27) | (1.29) | (1.41) | (1.33) | (1.36) |
| Roe | 1.0858 *** | 0.9718 *** | 0.9909 *** | 1.1801 *** | 1.1149 *** | 1.0358 *** | 1.0354 *** |
| | (15.11) | (23.36) | (23.26) | (20.43) | (19.45) | (24.83) | (24.82) |
| Lev | 0.4891 *** | 0.4369 *** | 0.3688 *** | 0.3386 *** | 0.3846 *** | 0.3888 *** | 0.3910 *** |
| | (6.34) | (12.26) | (9.02) | (7.50) | (8.79) | (10.53) | (10.55) |
| Cgdp | −0.0001 | −0.0030 * | −0.0041 ** | −0.0010 | −0.0006 | −0.0038 ** | −0.0039 ** |
| | (−0.04) | (−1.87) | (−2.40) | (−0.43) | (−0.27) | (−2.29) | (−2.35) |
| Pgdp | −0.0379 | −0.0559 | −0.0785 ** | 0.0319 | 0.0241 | −0.0470 | −0.0558 * |
| | (−0.51) | (−1.62) | (−2.14) | (−0.60) | (0.45) | (−1.45) | (−1.69) |
| _cons | −1.2899 | −3.1250 *** | −0.8782 | −1.9709 ** | −3.8655 *** | −1.4185 ** | −1.3610 ** |
| | (−1.09) | (−5.20) | (−1.38) | (−2.38) | (−4.53) | (−2.37) | (−2.26) |
| Year | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Stkcd | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 6684 | 13,332 | 12,119 | 9696 | 9696 | 13,332 | 13,332 |
| $R^2$ | 0.9095 | 0.9418 | 0.9131 | 0.9141 | 0.9446 | 0.9103 | 0.9103 |

*t* statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

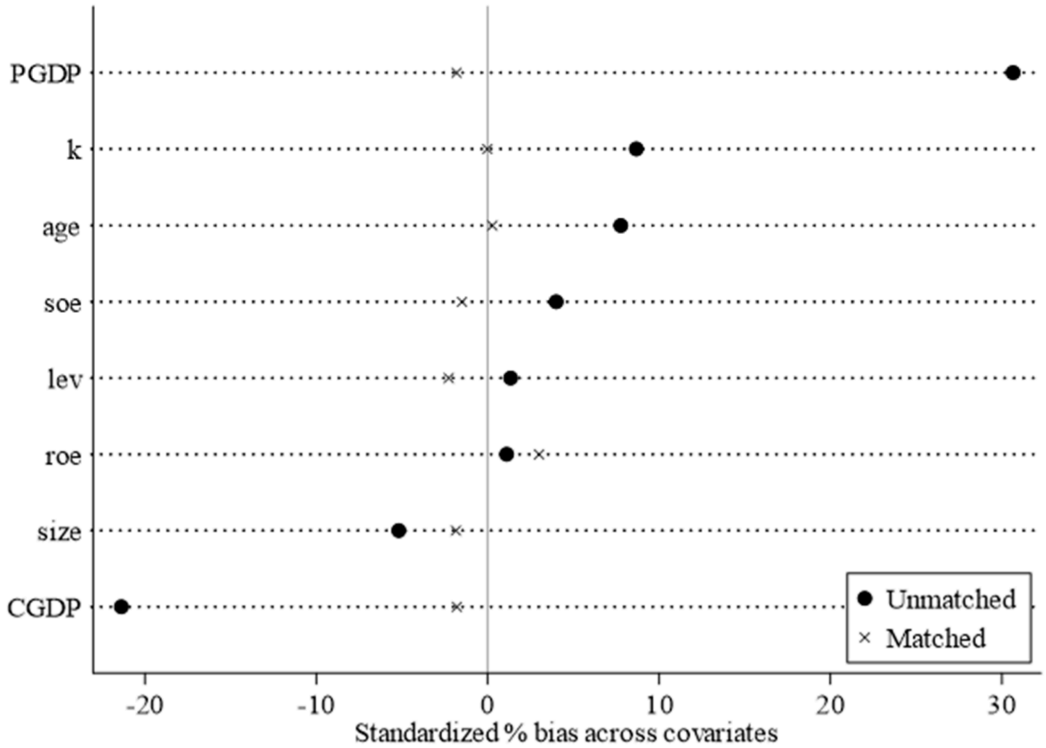



**Figure 6.** Balance Test Results.

4.3.4. Alternative Measurement of TFP

When estimating firms' TFP, it is important to note that although the OP method effectively mitigates simultaneity and selection bias, it relies on investment as a proxy variable. As a result, observations with negative investment values are excluded, leading to substantial sample attrition. To address this issue, we also employ the Levinsohn and Petrin (2003) [65] approach (LP method) as a robustness check. Building on the OP framework, the LP method substitutes intermediate inputs for investment as the proxy variable, thereby alleviating the problem of sample loss. This substitution reduces attrition, improves the efficiency of data utilization, and enhances the reliability of the TFP estimates.

Column (2) of Table 4 reports the regression results based on TFP estimated using the LP method. The results indicate that, after including control variables, the estimated coefficient of the VMR-EPA policy is −0.0353, which remains significantly negative at the 1% level. This finding suggests that the VMR-EPA policy significantly suppresses firms' TFP, and the result is robust even when the measurement of the dependent variable is changed.

Furthermore, to further address the issue that the method used to calculate firm-level total factor productivity may affect the estimation results, this paper first estimates firm-level total factor productivity using the OP method and the LP method in the baseline regression. It then recalculates firm-level total factor productivity using the fixed-effects method (FE), generalized method of moments (GMM), and ordinary least squares (OLS), and uses these estimates as dependent variables in separate regression tests.

Table 5 reports the regression results following the change in the TFP estimation method. In Column (1), with TFP-FE estimated using the fixed-effects method as the dependent variable, the estimated coefficient for the variable representing the vertical management reform of environmental protection agencies (did) is −0.0315, and is significant at the 1% level; in Column (2), with TFP-GMM estimated using the GMM method as the dependent variable, the estimated coefficient of did is −0.0414, which is also significantly negative at the 1% level; and in Column (3), with TFP-OLS estimated using the OLS method as the dependent variable, the estimated coefficient of did is −0.0329, and is significant at the 1% level. The above results indicate that regardless of whether firm-level TFP is re-estimated using the fixed-effects method, the GMM method, or the OLS method, the impact of the vertical management reform of environmental protection agencies on firm-level TFP is significantly negative, consistent with the results of the baseline regression. Therefore, the core conclusion of this paper does not depend on the specific estimation methods of the OP method or the LP method. Even when using other productivity measurement metrics, the vertical management reform of environmental protection agencies still significantly suppresses enterprise TFP, indicating that the findings of this study possess good robustness.

**Table 5.** Robustness Test Results 2.

| | **(1)**<br>**TFP-FE** | **(2)**<br>**TFP-GMM** | **(3)**<br>**TFP-OLS** |
|---|---|---|---|
| VMR-EPA | −0.0315 *** | −0.0414 *** | −0.0328 *** |
| | (−3.56) | (−4.45) | (−3.74) |
| Size | 0.7378 *** | 0.2731 *** | 0.6819 *** |
| | (69.05) | (23.28) | (64.01) |
| Age | 0.0650 *** | 0.0848 *** | 0.0662 ** |
| | (2.17) | (2.90) | (2.26) |
| K | 0.1626 *** | −0.1.0807 *** | −0.0247 |
| | (3.26) | (−21.33) | (0.55) |

**Table 5.** *Cont.*

| | (1) TFP-FE | (2) TFP-GMM | (3) TFP-OLS |
|---|---|---|---|
| Soe | 0.0434 ** | 0.0353 * | 0.0447 ** |
| | (2.16) | (1.67) | (2.21) |
| Roe | 0.9454 *** | 1.0260 *** | 0.9561 *** |
| | (22.90) | (24.28) | (23.32) |
| Lev | 0.4569 *** | 0.4058 *** | 0.4523 *** |
| | (13.14) | (10.87) | (13.03) |
| Cgdp | −0.0013 | −0.0043 *** | −0.0017 |
| | (−0.86) | (−2.56) | (−1.07) |
| Pgdp | −0.0446 | −0.5577 | −0.0491 * |
| | (1.40) | (1.61) | (−1.53) |
| -cons | −5.8261 *** | −0.7766 | −5.1700 ** |
| | (9.75) | (−1.29) | (−8.74) |
| Year | Yes | Yes | Yes |
| Stkcd | Yes | Yes | Yes |
| N | 13,332 | 13,332 | 13,332 |
| $R^2$ | 0.9633 | 0.9018 | 0.9593 |

*t* statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

#### 4.3.5. Lagged Explanatory Variable

Lagging the explanatory variable by one period establishes the temporal ordering between the explanatory and dependent variables, thereby partially ensuring causality and mitigating potential endogeneity concerns (Arellano and Bond, 1991) [81]. Furthermore, given that the reform of the vertical management system for environmental protection agencies may not have been fully implemented during the early stages of policy implementation, it is difficult to accurately identify its immediate economic effects. Therefore, this paper incorporates the policy variable with a one-period lag into the model to capture the delayed effects of the policy and reduce estimation biases that may arise from contemporaneous shocks. Column (3) of Table 4 reports the estimation results from the regression using the policy variable with a one-period lag. The results show that the estimated coefficient for the VMR-EPA policy variable is −0.0312, and remains significantly negative at the 1% significance level. This result indicates that, even after accounting for potential contemporaneous effects, the reform of the vertical management system for environmental protection agencies still exerts a significant inhibitory effect on firms' total factor productivity, further validating the robustness of the baseline regression results.

#### 4.3.6. Alternative Sample Period

The outbreak of COVID-19 at the end of 2019 had profound impacts on the global economy and caused severe shocks to Chinese firms (Cooper et al., 2022; He et al., 2020) [82,83]. To control for potential confounding effects of the COVID-19 pandemic on firms' total factor productivity, this study excludes the 2019–2021 sample—which was severely impacted by the pandemic—and re-estimates the model. Columns (4) and (5) of Table 4 report the corresponding regression results. The results show that the estimated coefficients for the VMR-EPA policy variable are −0.0413 and −0.0365, respectively, and both are statistically significant at the 1% level. These findings indicate that, even after excluding samples from the pandemic period, the reform of the vertical management system for environmental protection agencies continues to exert a significant negative impact on firms' total factor productivity.

4.3.7. Excluding the Influence of Other Concurrent Policies

To control for potential confounding effects of other policy interventions implemented during the same period, we incorporate the Low-Carbon City Pilot (LCCP) policy (Chen et al., 2021) [84] and the Environmental Damage Compensation Reform Pilot (EDCRP) (Zhou et al., 2023) [85] as additional covariates in the regression model. Columns (6) and (7) of Table 4 report the results. When the LCCP variable is included, the coefficient of the VMR-EPA policy is −0.0428 ($p < 0.01$). When the EDCRP variable is added, the coefficient of the VMR-EPA policy is −0.0456 ($p < 0.01$). These findings indicate that even after controlling for the influence of other concurrent policy interventions, the negative effect of the vertical management reform of environmental protection agencies on firms' TFP remains statistically significant and robust.

Looking further, the low-carbon city pilot program and the reform of the ecological and environmental damage compensation system are primarily manifested as specific environmental policy tools or accountability mechanisms, whereas the core of the reform of the vertical management of environmental protection agencies lies in reshaping the allocation of environmental governance authority, enhancing the independence of monitoring, supervision, and law enforcement, and reducing interference from local governments. Even after controlling for the effects of other environmental policies, the VMR-EPA coefficient remains significantly negative, indicating that what this study identifies is not a general cumulative effect of environmental policies, but rather the independent impact of environmental governance structural reform itself on firm productivity. This further enhances the robustness and identification credibility of the study's conclusions.

### *4.4. Mechanism Analysis*

The above results indicate that the vertical management reform of environmental protection agencies significantly suppresses firms' total factor productivity (TFP). An important question that follows is: through which mechanisms does this policy exert its impact? Building on the preceding theoretical analysis, this study investigates the underlying channels from two perspectives—technological innovation capacity and capital allocation efficiency—through which the reform influences firms' TFP.

4.4.1. Technological Innovation Capacity

Schumpeter's theory of "creative destruction" posits that the weakening of innovation capacity hinders the dynamic efficiency improvement process whereby firms eliminate inefficient production capacity through technological innovation (Assink, 2006; Guan et al., 2006) [86,87]. To further verify whether technological innovation capacity plays a mediating role in the relationship between the vertical management reform of environmental protection agencies and firms' TFP, we construct the following mediation effect model:

$$RD_{i,t} = \alpha_0 + \beta_0 VMR - EPA_{s,t} + \gamma_0 X_{i,t} + \delta_t + \varphi_i + \nu_{i,t} \quad (4)$$

In Equation (4), the dependent variable $RD_{i,t}$ represents firms' technological innovation capacity. Considering the time lag of patents, we measure this by the ratio of R&D expenditure to net fixed assets; a higher ratio indicates stronger technological innovation capacity. The coefficient $\beta_0$ captures the effect of the *VMR-EPA* policy on firms' technological innovation capacity. Other variable definitions remain consistent with Model (1).

We adopt a two-step approach to test the mediating effect. If $\beta_0$ is significant, it indicates that the *VMR-EPA* policy significantly affects firms' technological innovation capacity, which in turn influences TFP. As shown in Column (1) of Table 6, the coefficient $\beta_0$ is significantly negative at the 1% level, confirming that technological innovation capacity serves as a mediator. Specifically, after the implementation of the vertical management

reform, firms' technological innovation capacity is suppressed, thereby reducing their TFP. This finding supports Hypothesis 2.

In addition, to further address potential endogeneity issues in the mechanism analysis, this study employs the number of corporate invention patent applications (IP) and the number of R&D personnel (RDP) as supplementary proxy variables to simultaneously capture both corporate innovation output and human capital investment in innovation. The regression results in columns (2) and (3) of Table 6 show that when the number of corporate invention patent applications is used as the dependent variable, the estimated coefficient of the variable did (representing the vertical management reform of environmental protection agencies) is −7.4287, and is significant at the 1% level; when the number of R&D personnel is used as the dependent variable, the estimated coefficient of did is −103.4596, which is also significantly negative at the 1% level. This indicates that the vertical management reform of environmental protection agencies not only suppresses firms' R&D intensity but also exerts a significant negative impact on their innovation output and R&D personnel allocation. This suggests that under stricter and more independent environmental regulatory constraints, firms may allocate more resources to environmental compliance, pollution control, and regulatory response activities, thereby crowding out human and financial resources that would otherwise be available for technological innovation, and consequently weakening their technological innovation capabilities.

**Table 6.** Mechanism Analysis Results.

| | (1)<br>RD | (2)<br>IP | (3)<br>RDP | (4)<br>Invest | (5)<br>Invest |
|---|---|---|---|---|---|
| VMR-EPA | −0.0322 ** | −7.4287 *** | −1.0345 *** | | |
| | (−2.16) | (3.18) | (−4.87) | | |
| Treat × Time × Q | | | | −0.0040 *** | −0.0039 *** |
| | | | | (−2.81) | (−2.76) |
| Treat × Time | | | | 0.0082 *** | 0.0079 *** |
| | | | | (2.92) | (2.80) |
| Treat × Q | | | | 0.0030 *** | 0.0022 ** |
| | | | | (3.47) | (2.32) |
| Time × Q | | | | 0.0037 ** | 0.0026 |
| | | | | (2.30) | (1.62) |
| Size | −0.0158 | 32.2343 *** | 4.5054 *** | | 0.0073 *** |
| | (−0.34) | (9.41) | (15.40) | | (6.07) |
| Age | 0.0132 | −4.8336 | 0.7921 ** | | −0.0049 ** |
| | (0.67) | (−0.71) | (2.13) | | (−2.04) |
| K | −1.0953 *** | −4.6769 | 1.9913 ** | | −0.0550 *** |
| | (−3.64) | (−0.55) | (2.07) | | (−7.03) |
| Soe | 0.0050 | −9.3550 ** | −1.9641 *** | | −0.0032 |
| | (0.11) | (−2.52) | (−3.53) | | (−1.49) |
| Roe | −0.3251 | −13.5977 ** | −2.2199 *** | | 0.0138 *** |
| | (−1.63) | (−2.11) | (−3.54) | | (3.58) |
| Lev | −0.2491 *** | −39.9507 *** | −2.8088 *** | | 0.0013 |
| | (−3.92) | (−5.94) | (−4.50) | | (0.29) |
| Qt-1 | | | | | 0.0011 * |
| | | | | | (1.95) |
| Cgdp | −0.0018 ** | 0.2680 | −0.03751 | | −0.0003 * |
| | (−1.87) | (0.76) | (−0.99) | | (−1.80) |
| Pgdp | 0.0847 *** | 28.0719 *** | 3.4061 *** | | 0.0034 |
| | (2.77) | (3.63) | (4.35) | | (1.02) |
| -cons | −0.1725 | −900.6208 *** | −14.4248 *** | 0.0370 *** | −0.0792 |
| | (−0.17) | (−6.76) | (12.84) | (46.99) | (−1.47) |
| Year | Yes | Yes | Yes | Yes | Yes |
| Stkcd | Yes | Yes | Yes | Yes | Yes |
| N | 13,332 | 13,332 | 13,332 | 11,930 | 11,930 |
| $R^2$ | 0.4921 | 0.7983 | 0.6463 | 0.4508 | 0.4620 |

*t* statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.4.2. Capital Allocation Efficiency

The neoclassical investment theory posits that any deviation from the optimal allocation principle—where the marginal return to capital equals the marginal cost—will inevitably result in actual output falling short of its potential level, thereby impairing firms' efficiency (Machlup, 1946) [88]. In practice, a key benchmark for evaluating firms' capital allocation efficiency is whether their investment levels are aligned with their investment opportunities. Accordingly, the sensitivity of investment to investment opportunities serves as a direct and intuitive measure of capital allocation efficiency.

Building on the capital allocation efficiency model of (Wurgler, 2000) [89], this paper applies an "investment–investment opportunity sensitivity" framework to examine whether the vertical management reform of environmental protection agencies affects firms' TFP through the channel of capital allocation efficiency. The model is specified as follows:

$$\begin{aligned} Invest_{i,t} = \theta_0 + \theta_1 Treat_i \times Time_t \times Q_{i,t-1} + \theta_2 Treat_i \times Time_t + \theta_3 Tteat_i \times Q_{i,t-1} \\ + \theta_4 Time_t \times Q_{i,t-1} + \gamma X_{i,t} + \delta_t + \varphi_i + \varepsilon_{i,t} \end{aligned} \quad (5)$$

In Equation (5), $Invest_{i,t}$ denotes the firm's investment level in year $t$, measured as "(cash paid for the acquisition of fixed assets, intangible assets, and other long-term assets—cash received from the disposal of fixed assets, intangible assets, and other long-term assets)/total assets." $Q_{i,t-1}$ represents investment opportunities, measured primarily by the lagged Tobin's Q. $Treat_i$ is a policy dummy equal to 1 if the firm is affected by the reform, and 0 otherwise. $Time_t$ is a time dummy equal to 1 if the observation falls after the reform, and 0 otherwise. Other variable definitions are consistent with Model (1). The coefficient $\theta_1$ on the triple interaction term $Treat \times Time \times Q$ captures the effect of the reform on firms' investment efficiency. If $\theta_1 < 0$, it indicates that the vertical management reform of environmental protection agencies significantly reduces firms' resource allocation efficiency. The empirical results are reported in Table 4.

Columns (4) and (5) of Table 6 report the results. The coefficient on the triple interaction term $Treat \times Time \times Q$ is significantly negative at the 1% level. After introducing firm-level and regional-level control variables in Column (4), the coefficient of $Treat \times Time \times Q$ remains significantly negative. This indicates that, following the implementation of the vertical management reform of environmental protection agencies, firms in the treatment group experienced a significant decline in investment efficiency compared with those in the control group. These findings reveal that the reform adversely affects firms' TFP through the channel of capital allocation efficiency.

### *4.5. Further Analysis*

To examine whether the "innovation compensation effect" emphasized by Porter's hypothesis has an impact on this study, we further investigate whether the vertical management reform of environmental protection agencies can promote green innovation among firms. The Porter hypothesis posits that well-designed environmental regulations do not necessarily suppress firm productivity; rather, they may offset or even exceed the costs of environmental compliance by compelling firms to engage in technological innovation, improve resource efficiency, and drive green transformation. Therefore, if the vertical management reform of environmental protection agencies can significantly enhance firms' levels of green innovation, it implies that this institutional reform may exhibit a certain degree of innovation compensation effect.

Based on this, this paper further uses the number of green patent applications filed by firms as a proxy for their level of green innovation and treats it as the dependent variable, incorporating the variable representing the reform of the vertical management of environmental protection agencies into the regression model. The regression results

in Column (1) of Table 7 show that the estimated coefficient for the variable representing the reform of the vertical management of environmental protection agencies is −0.0121, which does not pass the conventional significance test. This indicates that, during the sample period of this study, the vertical management reform of environmental protection agencies did not significantly promote an increase in corporate green innovation levels; consequently, no significant green innovation compensation effect has been observed. This result suggests that, in the short term, the vertical management reform of environmental protection agencies is more likely to increase corporate compliance costs and governance pressures by strengthening the independence of environmental regulation and the rigidity of enforcement, rather than immediately stimulating corporate green innovation. Given that green innovation typically involves long investment cycles, high risks, and delayed commercialization, firms facing a sudden increase in regulatory intensity may prioritize end-of-pipe treatment, compliance expenditures, and short-term environmental management investments rather than engaging in green technological innovation that could enhance long-term productivity. Consequently, the empirical evidence in this study supports the dominance of compliance cost effects in the short term but fails to support the significant innovation compensation effect predicted by Porter's hypothesis.

**Table 7.** Further Analysis.

| | (1)<br>GI | (2)<br>TFP-OP | (3)<br>TFP-LP |
|---|---|---|---|
| VMR-EPA | −0.0121 | | |
| | (−0.96) | | |
| Post1 | | −0.0425 *** | −0.0386 ** |
| | | (2.51) | (−2.19) |
| Post2 | | −0.0640 *** | −0.0555 *** |
| | | (−3.58) | (−2.98) |
| Post3 | | −0.0651 *** | −0.0556 *** |
| | | (−3.29) | (−2.65) |
| Post4 | | −0.0616 *** | −0.0571 *** |
| | | (−2.81) | (−2.47) |
| Size | 0.0609 *** | | |
| | (4.83) | | |
| Age | 0.0376 | | |
| | (1.61) | | |
| K | −0.0460 | | |
| | (−0.84) | | |
| Soe | 0.0862 *** | | |
| | (2.77) | | |
| Roe | 0.0145 | | |
| | (0.35) | | |
| Lev | 0.0044 | | |
| | (0.11) | | |
| Cgdp | 0.0032 | | |
| | (1.66) | | |
| Pgdp | −0.0341 | | |
| | (−0.80) | | |
| -cons | −1.3148 ** | 6.8190 *** | 8.85294 *** |
| | (−2.27) | (1613.85) | (1971.49) |
| Year | Yes | Yes | Yes |
| Stckd | Yes | Yes | Yes |
| N | 13,332 | | |
| $R^2$ | 0.6975 | | |

*t* statistics in parentheses. ** $p < 0.05$, *** $p < 0.01$.

Furthermore, to address the question of whether the impact of the vertical management reform of environmental protection agencies on firms' total factor productivity is persistent, this paper employs an event study approach to examine the dynamic changes in the policy's effects. Specifically, using the year prior to policy implementation as the baseline period, this paper constructs dummy variables for the year of policy implementation and for the first through fourth years following implementation, and incorporates them into a baseline regression model to determine whether the impact of the vertical management reform on firms' total factor productivity fades over time.

The regression results in columns (2) and (3) of Table 7 show that when TFP-OP is the dependent variable, the estimated coefficient for the year of policy implementation is −0.0580, which is significant at the 1% level; the estimated coefficients for the first through fourth years following policy implementation are −0.0425, −0.0641, −0.0651, and −0.0617, respectively, all of which are significantly negative. When TFP-LP is the dependent variable, the estimated coefficient for the year of policy implementation is −0.0564, which is significant at the 1% level; the estimated coefficients for the first through fourth years following policy implementation are −0.0387, −0.0555, −0.0556, and −0.0571, respectively, all of which are significantly negative. These results indicate that, regardless of whether the OP method or the LP method is used to measure enterprise total factor productivity, the negative impact of the vertical management reform of environmental protection agencies on enterprise TFP persists after policy implementation.

These findings suggest that the impact of the vertical management reform of environmental protection agencies on firms' total factor productivity is not merely a short-term shock limited to the year of policy implementation, but rather exhibits a degree of persistence over the years following implementation. A likely reason is that the vertical management reform has strengthened the independence, uniformity, and rigidity of environmental regulation, causing firms to face persistently high environmental compliance costs and governance pressures. In the short term, firms must allocate more resources to pollution control, the upgrading of environmental protection equipment, and compliance management, thereby crowding out resources that would otherwise have been directed toward technological innovation and productivity improvements. In the medium term, investments in environmental protection-specific assets, adjustments to production processes, and changes in capital allocation structures may continue to affect firms' productivity. Therefore, the dynamic effects analysis in this paper further indicates that the dampening effect of the vertical management reform of environmental protection agencies on firms' total factor productivity exhibits a certain degree of persistence.

## 5. Heterogeneity Analysis

Before conducting the heterogeneity test, this paper first presents theoretical expectations based on three dimensions: enterprise ownership, regional governance capacity, and the existing regulatory foundation. First, state-owned enterprises typically bear greater responsibilities for policy responsiveness and environmental governance. Following the reform of vertical management in environmental protection agencies, they face stronger political accountability pressures, compliance requirements, and administrative constraints. Consequently, they are more likely to allocate resources to environmental compliance and pollution control activities, which in turn exerts a more pronounced dampening effect on productivity. Second, the eastern region features a higher degree of marketization, stronger environmental enforcement capabilities, and more robust social oversight and information disclosure mechanisms. Consequently, the vertical management reform is more likely to translate into actual regulatory pressure in this region, resulting in a stronger compliance shock for enterprises. Finally, for firms that had a weak regulatory foundation

prior to the reform, the vertical management reform significantly reduced the scope for local protectionism and selective enforcement, causing their existing "weak regulation dividend" to rapidly disappear; consequently, the marginal impact of the policy shock is greater. Based on the above analysis, this paper expects that the vertical management reform of environmental protection agencies will have a more pronounced suppressing effect on total factor productivity for state-owned enterprises, firms in the eastern region, and firms with weak regulatory oversight.

### *5.1. Ownership-Based Heterogeneity*

The sample is partitioned into state-owned enterprises (SOEs), private enterprises, and foreign-funded enterprises, and regressions are estimated separately for each group. Columns (1) and (2) of Table 8 report *VMR-EPA* coefficients of −0.0656 and −0.0261, significant at the 1% and 10% levels, respectively. These results suggest that the vertical management reform of environmental protection agencies significantly depresses TFP in both SOEs and private firms, with the effect being more pronounced among SOEs. By contrast, Column (3) shows a coefficient of 0.051 for foreign-funded enterprises, which is statistically insignificant, indicating that the reform has no measurable impact on their productivity. Taken together, the evidence implies that relative to non-SOEs, the vertical reform imposes a disproportionately stronger productivity penalty on state-owned enterprises.

**Table 8.** Heterogeneity Analysis: Firm Ownership.

| | (1) State-Owned Enterprise | (2) Private Enterprise | (3) Foreign-Invested Firm |
|---|---|---|---|
| VMR-EPA | −0.0656 *** | −0.0261 * | 0.051 |
| | (−4.59) | (−1.93) | (1.14) |
| Size | 0.3197 *** | 0.3420 *** | 0.1832 *** |
| | (17.77) | (20.21) | (2.80) |
| Age | 0.0800 *** | 0.066 | 0.0557 |
| | (2.63) | (0.50) | (0.88) |
| K | −0.3197 *** | −0.6550 *** | −1.182 *** |
| | (−4.77) | (−10.09) | (−5.77) |
| Roe | 1.0860 *** | 1.0457 *** | 0.4672 ** |
| | (17.14) | (17.22) | (2.24) |
| Lev | 0.2771 *** | 0.4438 *** | 0.3960 ** |
| | (4.55) | (8.27) | (2.38) |
| Cgdp | −0.0024 | −0.0062 ** | −0.0084 |
| | (−1.11) | (−2.06) | (−1.09) |
| Pgdp | −0.0842 ** | −0.0785 | −0.0014 |
| | (−2.30) | (−1.10) | (−0.01) |
| -cons | −0.8938 | −0.8961 | −1.9091 |
| | (−1.19) | (−0.54) | (0.53) |
| Year | Yes | Yes | Yes |
| Stkcd | Yes | Yes | Yes |
| N | 6084 | 6340 | 633 |
| $R^2$ | 0.9188 | 0.8900 | 0.9073 |

*t* statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

This divergence mainly arises from differences in organizational flexibility associated with ownership structure. According to the theory of organizational ambidexterity (Tushman and O'Reilly, 1996) [90], non-SOEs possess greater autonomy and agility in strategic decision-making, enabling them to quickly adjust investment priorities and allocate resources more efficiently. By contrast, SOEs not only face market pressures but

also carry government-imposed mandates such as maintaining employment stability and supporting economic growth. These additional responsibilities often force SOEs to deviate from efficiency-oriented investment principles, leading to greater distortions in capital allocation. Moreover, investment decisions in SOEs are typically subject to approval by the State-owned Assets Supervision and Administration Commission (SASAC) or local governments, slowing down their policy responses. As a result, SOEs are constrained by complex decision-making procedures, resource allocation inertia, and lengthy evaluation cycles, all of which weaken their adaptability to changing conditions and undermine their efficiency.

### *5.2. Regulatory Intensity Perspective*

Following the Catalogue for Classified Administration of Environmental Verification of Listed Companies by Industry (2008), the Comprehensive Catalogue for Environmental Protection (2021 Edition), and the Guidelines for the Classification of Listed Companies by Industry (2012 Revision), we classify industries subject to high environmental regulatory intensity as those in mining (Code B), manufacturing (Code C), and electricity, heat, gas, and water production and supply (Code D). Specifically, based on nineteen major industry codes, firms are categorized into the high-intensity group if they fall within the following sectors: B06, B07, B08, B09, C17, C19, C22, C25, C26, C27, C28, C30, C31, C32, C33, and D44). Accordingly, the sample is divided into firms operating in high- and low-intensity regulatory environments. Regression results are presented in Columns (1) and (2) of Table 9. For firms in industries with lower regulatory intensity, the coefficient of VMR-EPA is −0.0393 and statistically significant at the 1% level. For firms in high-intensity industries, the coefficient is −0.0357 and significant at the 5% level. These findings suggest that the negative effect of the vertical management reform of environmental protection agencies is more pronounced for firms in industries with relatively low regulatory intensity.

**Table 9.** Heterogeneity Analysis: Environmental Regulation Intensity and Regional Location.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | **Environmental Regulation Intensity** | | **Regional Location** | |
| | **Low** | **High** | **Eastern** | **Non-Eastern** |
| VMR-EPA | −0.0393 *** | −0.0357 ** | −0.0564 *** | −0.0096 |
| | (−3.43) | (−2.27) | (−5.17) | (−0.49) |
| Size | 0.3409 *** | 0.2932 *** | 0.3323 *** | 0.3235 *** |
| | (22.72) | (15.07) | (22.83) | (16.58) |
| Age | 0.0581 * | 0.1098 ** | 0.0854 *** | 0.1051 |
| | (1.65) | (2.20) | (2.73) | (1.08) |
| K | −0.6329 *** | −0.3478 *** | −0.4352 *** | −0.7257 *** |
| | (−8.61) | (−5.69) | (−6.99) | (−9.64) |
| Soe | 0.0674 *** | −0.0971 ** | 0.0478 * | 0.0096 |
| | (2.86) | (−2.38) | (1.93) | (0.21) |
| Roe | 0.9895 *** | 1.0209 *** | 1.0387 *** | 1.0094 *** |
| | (18.74) | (15.62) | (20.10) | (14.25) |
| Lev | 0.4930 *** | 0.1827 *** | 0.3608 *** | 0.4528 *** |
| | (10.26) | (3.09) | (8.26) | (6.50) |
| Cgdp | −0.0033 | −0.0050 * | −0.0041 * | −0.0044 * |
| | (−1.64) | (−1.92) | (−1.92) | (−1.77) |
| Pgdp | −0.0589 | −0.0254 ** | −0.2155 *** | 0.1425 ** |
| | (−1.31) | (−0.55) | (−4.52) | (2.45) |
| -cons | −3.1250 * | −1.0875 | 0.5080 | −3.7972 ** |
| | (−1.68) | (−1.10) | (0.71) | (−2.27) |
| Year | Yes | Yes | Yes | Yes |
| Stkcd | Yes | Yes | Yes | Yes |
| N | 9004 | 4323 | 9316 | 4012 |
| $R^2$ | 0.9129 | 0.9120 | 0.9110 | 0.9084 |

*t* statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

This difference can be explained by the Porter Hypothesis (Porter and Linde, 1995) [13], which posits that effective environmental regulations stimulate firms' innovation activities, ultimately offsetting compliance costs and enhancing profitability (Luo et al., 2022) [91]. Firms in highly regulated industries have long invested in environmental technological upgrades, accumulated pollution control patents, and developed efficient end-of-pipe treatment processes, making the new reform only a marginal adjustment. Moreover, these firms often maintain comprehensive environmental management systems (e.g., ISO 14001 certification) and employ dedicated environmental teams, enabling them to respond quickly and adjust effectively to policy changes. In contrast, firms in weakly regulated industries typically suffer from low utilization rates of environmental facilities, underdeveloped circular economy practices, and limited access to green finance. As a result, when confronted with the new policy shock, they experience a more substantial negative impact.

### *5.3. Regional Location Perspective*

China's regions exhibit substantial differences in economic development, resource allocation, and institutional frameworks, which lead to heterogeneous effects of the VMR-EPA policy on firms' TFP. To capture these differences, the sample is divided into eastern and non-eastern regions, and regressions are conducted separately for each subsample. The results are reported in Table 9, Columns (3) and (4). In the eastern region, the coefficient of *VMR-EPA* is −0.0564, significant at the 1% level, while in the non-eastern regions, the coefficient is −0.0096 and statistically insignificant. These findings suggest that the negative impact of the VMR-EPA policy on firms' TFP is more pronounced in the eastern region than in the non-eastern regions.

Two main factors account for these differences. First, the eastern region is characterized by a more developed rule-of-law environment, stronger government enforcement capacity, and more active social supervision. Under vertical management, policies are implemented more rigorously, environmental law enforcement is more independent, and administrative discretion is more limited. Firms face "hard constraints," and local governments have little room to shield enterprises through discretionary protection, sharply increasing compliance pressures. In contrast, environmental agencies in central and western regions face shortages of personnel, technology, and equipment, which restrict their monitoring capacity. Moreover, economic growth and employment stability remain priority objectives, and local governments may weaken the policy's impact through informal channels, particularly for pillar enterprises. This fosters stronger local protectionist networks, and vertical management agencies may be compelled or inclined to seek compromises. Second, eastern regions are dominated by technology-intensive and export-oriented enterprises, where labor costs, land costs, and environmental compliance costs account for a large share of total expenses. When environmental regulations tighten, the high industrial concentration and resource scarcity (land and labor) leave firms with little room for relocation or production adjustments. Additional compliance costs thus directly squeeze already thin profit margins. By contrast, central and western regions are dominated by resource-intensive and domestically oriented enterprises, where energy and raw material costs account for a larger proportion, making them relatively less sensitive to rising environmental costs. Stricter regulations may instead accelerate "pollution gradient transfer," allowing affected firms to relocate across regions to mitigate compliance pressures, thereby preventing significant declines in TFP.

## 6. Conclusions and Policy Recommendations

### *6.1. Conclusions*

Using panel data of Chinese A-share-listed firms from 2012 to 2022, this study empirically examines the impact of the vertical management reform of environmental protection agencies on firms' total factor productivity (TFP). The main findings are as follows: first, the reform significantly reduces the TFP of firms in pilot regions, and this result remains robust after a series of robustness checks, including sensitivity analysis, placebo tests, Bacon decomposition, and PSM-DID. Second, the reform suppresses firms' TFP primarily by weakening technological innovation and distorting capital allocation efficiency. Finally, heterogeneity analysis shows that the negative effect of the reform is more pronounced for state-owned enterprises, firms in weakly regulated industries, and firms located in eastern regions.

### *6.2. Policy Recommendations*

Based on these findings, the following policy recommendations are offered:

(1) Improve supporting mechanisms for reform to alleviate short-term compliance pressures on businesses

The vertical management reform of environmental protection agencies helps reduce local protectionism and enhance the independence and effectiveness of environmental regulation; however, empirical evidence suggests that it may have a certain dampening effect on firms' total factor productivity in the short term. Therefore, when advancing reforms to the environmental governance structure, policymakers should avoid fostering a policy bias that "prioritizes regulation over support." Based on enterprises' pollution intensity, financial capacity, and foundation for transformation, policymakers should explore differentiated mechanisms for fiscal support, tax incentives, green credit, and environmental technology services to help enterprises smoothly complete the upgrading of environmental protection equipment and adjustments to compliance management. In particular, for enterprises facing severe resource constraints and weak financing capabilities, more targeted transitional support should be provided to mitigate the short-term crowding-out effect of compliance costs on R&D investment and production efficiency.

(2) Promote synergy between environmental regulation and incentives for green innovation to facilitate the realization of the benefits of innovation

This study finds that the vertical management reform of environmental protection agencies did not significantly promote corporate green innovation during the sample period, suggesting that relying solely on regulatory pressure does not necessarily lead to productivity gains. Future policy design should strengthen the independence of law enforcement while further refining incentive mechanisms for green technological innovation. For example, measures such as green R&D subsidies, loans for environmental technology upgrades, support for the commercialization of green patents, and incentives for green supply chains could be employed to guide enterprises toward shifting from end-of-pipe compliance to process upgrades and clean technology innovation. Policy priorities should not be limited to meeting pollution standards and enforcement penalties; rather, they should leverage the synergy between market-based tools and institutional regulation to encourage enterprises to transform environmental pressures into drivers of technological upgrading and efficiency improvements.

(3) Optimize capital allocation mechanisms to reduce resource misallocation caused by environmental compliance requirements

Mechanism tests indicate that reforms to the vertical management of environmental protection agencies may affect firms' total factor productivity by reducing the efficiency of capital allocation. Therefore, environmental governance reforms need to be coordinated with policies in the financial, industrial, and factor markets. On the one hand, efforts should be made to incorporate environmental performance, investment in green technologies, and governance outcomes into the risk assessment and credit approval systems of financial institutions, thereby providing more stable financing support to enterprises with strong environmental performance and a strong willingness to transition. On the other hand, we should avoid simply replacing market-based resource allocation with environmental constraints, and prevent capital from flowing excessively into inefficient end-of-pipe treatment projects. In industrial clusters, industrial parks can be encouraged to jointly build and share environmental infrastructure such as wastewater treatment, pollution monitoring, and solid waste disposal facilities. By leveraging economies of scale, this approach reduces the compliance burden on individual enterprises, thereby mitigating the duplicate investments and resource waste that may result from decentralized pollution control efforts.

(4) Implement differentiated regulation to avoid the negative impact of "one-size-fits-all" policies

Heterogeneous results indicate that the reform has had a more significant impact on state-owned enterprises, firms with weak regulatory compliance, and enterprises in the eastern region. Therefore, policy implementation requires fine-tuning based on enterprise type and regional characteristics. For state-owned enterprises, while strengthening environmental accountability, greater emphasis should be placed on the efficiency of environmental investments and the effectiveness of technological upgrades, to prevent them from merely increasing compliance expenditures as a response to regulatory pressure. For enterprises with a weak regulatory foundation prior to the reform, compliance guidance, technical training, and disclosure requirements should be strengthened to help them gradually adapt to a stricter environmental governance system. For enterprises in the eastern regions and industrial clusters, greater attention should be paid to the impact of high factor costs, high compliance costs, and supply chain pressures on corporate productivity. Regional collaborative governance, public environmental facilities in industrial parks, and green technology service platforms should be leveraged to mitigate the concentrated impact of policy shocks. In central and western regions, efforts to enhance regulatory capacity must be balanced with measures to prevent pollution displacement and the resurgence of local protectionism.

(5) Promote reforms in the vertical management of environmental protection, shifting the focus from strengthening law enforcement to improving governance effectiveness

The institutional value of the vertical management reform of environmental protection agencies lies not only in strengthening the rigor of environmental oversight but also in enhancing the effectiveness of environmental governance through the restructuring of governance mechanisms. In the future, a balance must be maintained between provincial-level coordination and grassroots-level implementation. While ensuring the independence and authority of monitoring, supervision, and law enforcement, it is also essential to strengthen the capacity of grassroots environmental protection departments in terms of personnel, technology, and data management to avoid the problem of "strengthened provincial-level coordination but weakened grassroots-level implementation." At the same time, efforts should be made to encourage the joint participation of the government, enterprises, the public, and third-party institutions in environmental governance. Through environmental information disclosure, third-party monitoring, public oversight, and corporate environ-

mental responsibility assessments, the transparency and predictability of environmental governance can be improved. Only by establishing effective synergy among institutional rigidity, market incentives, and public oversight can the reform of vertical management in environmental protection be transformed from institutional restructuring into enhanced governance effectiveness.

### *6.3. Limitations of the Study and Directions for Future Research*

First, this study uses companies listed on the Shanghai and Shenzhen A-share markets in China as its research sample. Since listed companies are typically large in scale, adhere to standardized information disclosure practices, and have relatively abundant financing channels, the findings of this study are primarily applicable to the population of listed companies. For unlisted companies, small and medium-sized enterprises (SMEs), and private enterprises with limited financing capacity, the impact of the reform of the vertical management of environmental protection agencies may be more complex; therefore, caution should be exercised when generalizing the conclusions of this study to these enterprises.

Second, this study examines the institutional shock resulting from China's environmental governance structural reforms, and its conclusions are to some extent context-dependent. The reform of vertical management of environmental protection agencies is built upon China's specific central–local relations, administrative accountability system, and environmental governance framework; therefore, the findings of this study may not be directly applicable to other countries or governance systems. Future research could further compare the policy effects of environmental governance structural reforms across different countries to test the applicability of these conclusions in diverse institutional environments.

Third, although this study has made every effort to mitigate identification bias through pre-policy trend tests, sensitivity analyses, PSM-DID, Bacon decomposition, and various robustness tests, the pilot provinces for the vertical management reform of environmental protection agencies were not selected entirely at random, and unobserved regional characteristics may still exert an influence. Future research could further integrate finer-grained data on firm-level emissions, enforcement penalties, environmental inspection activities, and local government behavior to more accurately identify the mechanisms underlying environmental governance structural reforms.

Fourth, the mechanism tests in this paper primarily provide empirical evidence regarding technological innovation capacity and capital allocation efficiency; however, there may be a bidirectional relationship between these factors and firms' total factor productivity. Therefore, this paper does not interpret the mechanism tests as strict causal mediation identification. Future research could utilize data with longer time spans, higher frequency, or exogenous instrumental variables to further identify the dynamic mechanisms through which environmental governance reforms affect firm innovation, investment, and productivity.

Fifth, the sample period of this study allows for the observation of short- to medium-term effects in the years following the implementation of reforms, but observations regarding longer-term green technology accumulation, industrial restructuring, and innovation compensation effects remain limited. As the data time window expands in the future, it will be possible to further examine whether firms will gradually offset short-term compliance costs over a longer period through green innovation, production process optimization, and management improvements, thereby achieving a dynamic coordination between environmental governance and productivity enhancement.

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