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Does vertical supervision enhance labor productivity? Evidence from China's central environmental protection inspection

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Vertical supervision is an important institutional arrangement for overcoming the principal-agent problem between central and local governments within political decentralization. This research employs panel data from Chinese A-share listed firms spanning 2012–2019, utilizing the Central Environmental Protection Inspection (CEPI) as an exogenous shock. Through the application of the staggered difference-in-difference approach, the study investigates the effect of vertical supervision on labor productivity. Our findings indicate that CEPI significantly promotes labor productivity. We identify three possible mechanisms driving this positive effect: increasing local government environmental governance's willingness, intensity, and effectiveness. The analysis of heterogeneity indicates that the enhancing effect of vertical supervision on labor productivity is more pronounced within state-owned enterprises, regions characterized by lower resource dependency, and regions equipped with more robust environmental regulation. This study deepens our understanding of vertical supervision effectiveness in environmental governance and provides valuable insights for policymakers to improve regulatory frameworks.

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Introduction

Political decentralization is typically regarded as an effective means to improve the provision of public goods based on local needs and conditions (Tiebout 1956). In the realm of environmental governance, decentralized administrative frameworks often exhibit reduced operational effectiveness (Zhang et al. 2018). Local governments, in pursuit of economic benefits, have an incentive to selectively enforce central policies and potentially tolerate or conceal environmental violations, significantly undermining the effectiveness of environmental governance (McAusland 2003; Liu and Diamond 2005; Kunce and Shogren 2005). The central government's vertical supervision plays a crucial role in tackling these issues (Zhang et al. 2018), as it guarantees the uniform enforcement of environmental regulations via administrative authority and alleviates the negative impacts of local protectionism on environmental governance.

The central environmental protection inspection (CEPI) exemplifies a vertical supervision policy in China (Zeng et al. 2023), transitioning the emphasis from "supervising firms" to "supervising the government" (Li et al. 2023). Unlike other environmental policies, CEPI is characterized by stringent supervisory measures and a top-down enforcement mechanism (Kopyrina et al. 2023). Its core objective is to address the principal-agent issue in local government environmental governance by enhancing direct central supervision, thereby ensuring the thorough and efficient execution of environmental policies (Wang et al. 2021). Based on this, existing research has extensively examined the role of CEPI in enhancing environmental quality (Jia and Chen 2019; Lin et al. 2021; Razzaq et al. 2023), while studies focusing on its economic outcomes remain comparatively limited. Given that environmental protection can be seen as an investment in human capital (Zivin and Neidell 2012), our research explores the microeconomic implications of CEPI through the lens of labor productivity.

Labor productivity serves as a critical measure of economic performance, capturing the efficiency of labor inputs in generating goods and services (Chang et al. 2016). Prior research has examined the determinants of labor productivity from multiple perspectives, such as technological advancement (Solow 1956), worker quality (Schultz 1961), and human resource management (Datta et al. 2005), while recent research increasingly focusing on the impact of environmental quality on worker labor performance (Zivin and Neidell 2012; Chang et al. 2016; He et al. 2019). At the local government level, the factors affecting labor productivity mentioned above are constrained by poor local governance, causing labor productivity to fall below its natural level. In response, vertical supervision can mitigate these constraints through multiple channels. First, the CEPI imposes a top-down constraint, compelling local administrations to prioritize environmental concerns and enhancing their willingness to engage in environmental governance. Second, through direct supervision, CEPI alleviates local government interference with environmental departments, thereby strengthening the intensity of environmental governance. Third, by ensuring the comprehensive implementation and effective enforcement of environmental policies, the CEPI can enhance the quality of the local ecological environment, thereby boosting the effectiveness of environmental governance. Moreover, environmental improvements can enhance workers' health and job satisfaction, reduce absenteeism, and increase work efficiency (Chang et al. 2019), consequently boosting overall labor productivity.

Against the backdrop of CEPI, we examine the impact of vertical supervision on labor productivity. The findings show that CEPI significantly improves firm labor productivity, indicating that vertical supervision can effectively promote labor productivity. This finding is still valid after mitigating potential endogeneity problems. We also find that CEPI enhances labor productivity by increasing local government environmental governance's willingness, intensity, and effectiveness. Additionally, the impact of vertical supervision on labor productivity is more pronounced in state-owned enterprises (SOEs), regions with lower resource dependency, and regions with better environmental legislation systems.

The contributions of this study are mainly manifested in the following dimensions: First, our study confirms that vertical supervision significantly alleviates the principal-agent issue between central and local authorities in the context of environmental management. Existing literature has recognized the limitations of environmental governance in a decentralized administration system (McAusland 2003; Kunce and Shogren 2005), but there is a lack of in-depth exploration on overcoming these limitations through effective institutional design. We empirically examine the positive role of vertical supervision in improving the environment and enhancing labor productivity, filling a gap in the existing research. Concurrently, this research offers theoretical foundations and practical insights for developing a more effective environmental regulatory framework and fostering alignment of environmental objectives between central and local authorities.

Second, this research broadens the scope of existing literature on the economic implications of CEPI. Prior studies have predominantly concentrated on investigating the environmental impacts of CEPI (Jia and Chen 2019; Lin et al. 2021; Razzaq et al. 2023), while comparatively less emphasis has been placed on its economic outcomes. A thorough evaluation of CEPI's policy impact necessitates a detailed exploration of its potential contributions to economic development, along with an understanding of its actual effects on the ecological environment. Consequently, this research investigates the economic consequences of CEPI through the lens of labor productivity. This approach assists policymakers in harmonizing environmental conservation with economic development and offers significant insights for refining regulatory structures in other regions and nations globally.

Third, this study enriches the research related to environmental protection and labor productivity. Current research has primarily concentrated on examining the effects of environmental protection on workers' health (Ostro 1983; Chay and Greenstone 2003; Carson et al. 2011), but has paid less attention to its economic implications and the effect on labor productivity. Indeed, the influence of environmental protection on labor productivity extends beyond direct health benefits, encompassing indirect benefits such as better workplace conditions, improved employee welfare, and heightened work efficiency. As such, we deeply analyze the actual effects of CEPI in enhancing labor productivity, revealing the potential mechanisms through which vertical supervision affects labor productivity and providing empirical evidence for how environmental protection can promote economic development.

Institutional background

Over the past decade, China has adopted an environmental governance model based on political decentralization. In this framework, the central government maintains its political control over environmental planning, whereas the main duties and execution of policies have been delegated to local governments (Li et al. 2020). However, local governments have exhibited a conspicuous lack of motivation to address environmental pollution due to the prevailing reliance on economic growth as the principal evaluation criterion for local officials (Li and Zhou 2005).

Table 1 Basic information of CEPI.

The round of CEPI	Duration	Inspected provinces
Pilot	2016.01.01–2016.01.31	Hebei
1st batch	2016.07.12–2016.08.19	Inner Mongolia, Heilongjiang, Jiangsu, Jiangxi, Henan, Ningxia, Yunnan, and Guangxi.
2nd batch	2016.11.24–2016.12.30	Beijing, Shanghai, Hubei, Guangdong, Chongqing, Shanxi, and Gansu.
3rd batch	2017.04.24–2017.05.28	Tianjin, Shanxi, Anhui, Liaoning, Fujian, Hunan, and Guizhou.
4th batch	2017.08.07–2017.09.15	Jilin, Zhejiang, Shandong, Hainan, Sichuan, Qinghai, Xinjiang, and Tibet.
Look-back	2018.05.30–2018.06.07	Hebei, Henan, Inner Mongolia, Ningxia, Heilongjiang, Jiangsu, Jiangxi, Guangdong, Guangxi, Yunnan, Shanxi, Liaoning, Jilin, Anhui, Shandong, Hubei, Hunan, Sichuan, Guizhou, and Shaanxi.

Consequently, it is often noted that the independence of environmental judiciary is compromised by local government intervention, leading to the prioritization of economic development over environmental protection (Zhang et al. 2019). To address the governance inefficiencies stemming from local governments' limited commitment to environmental governance under the decentralized administrative structure, the Chinese government has introduced the innovative CEPI policy. This initiative enables the central government to directly oversee local governments' environmental management efforts, thereby substantially propelling the reform of vertical supervision in China's environmental governance system (Zeng et al. 2023).

In 2015, the Central Committee of the Communist Party of China (CCCPC) and the State Council initiated a central inspection system to oversee and assess the enforcement of local environmental policies. In July 2015, the General Office of the CCCPC and the General Office of the State Council jointly issued the "Ordinance on Environmental Protection Inspection (Interim)." This regulation mandates the establishment of a central leading group to conduct environmental protection inspections across various provinces. Consequently, under the coordination of the CCCPC and the State Council, inspection teams led by ministerial-level officials were deployed to provincial party committees and provincial governments in four phases between 2016 and 2017. This policy is characterized by its extensive reach and rigorous implementation. As illustrated in Table 1, a pilot CEPI program commenced in January 2016, with Hebei Province undergoing a month-long environmental protection inspection. Subsequently, the first batch of formal inspections began in July–August 2016, with inspection teams stationed in eight provinces, including Inner Mongolia and Heilongjiang. In November 2016, the inspections expanded to administrative regions such as Beijing and Shanghai. From April to May 2017, the central inspection teams moved into seven provinces and cities, including Tianjin and Shanxi. Finally, from August to September 2017, the last batch of CEPI was completed in eight provinces, including Jilin and Zhejiang. To prevent the restart of polluting projects, the central inspectors conducted a "look-back" review in selected areas in 2018 to supervise rectification work, thereby establishing a long-term mechanism for environmental protection inspections (Jia and Chen 2019).

Upon arrival in a province, the central inspection teams conduct thorough evaluations. This includes listening to reports on environmental protection work, reviewing environmental monitoring data, having formal discussions with government officials and principals, conducting on-site inspections of cities, firms, and polluted areas, interviewing residents, and collecting complaints related to environmental issues (Ding et al. 2022). Following the conclusion of the inspection, the teams are required to deliver a detailed report on environmental concerns to the central authorities, specifying rectification requirements, urging local governments to implement corrective measures, and reporting their environmental governance actions to the public within a specified period. Furthermore, the results of CEPI are a key basis for the evaluation, political promotion, and rewards or punishments of officials, and those responsible for causing severe environmental damage may be handed over to national disciplinary and judicial authorities for further investigation. According to statistics, during the first batch of CEPI conducted from July to August 2016, 1140 government officials were severely penalized across the eight inspected provinces, including 130 department-level officials and 504 division-level officials. Across multiple rounds of CEPI, more than 212,000 public complaints have been promptly addressed, more than 40,000 firms have been penalized, 509 cases have been referred for investigation, and fines totaling over 40 million yuan have been imposed (Li et al. 2023). As stated, CEPI, directly supervised and managed by the central government, is a typical example of a vertical supervision policy that has effectively improved local governments' environmental protection efforts through rigorous inspection and feedback mechanisms.

CEPI significantly differs from conventional environmental regulatory policies as a vertical supervision mechanism. On the one hand, there is a difference in the inspection authorities: CEPI inspection teams are equipped with senior officials from the CCCPC, possessing the highest central administrative power. In practice, conventional environmental inspections are conducted by local departments under the Ministry of Environmental Protection. These agencies, often operating at the same administrative level as local government officials, lack the independence to effectively oversee local governments' environmental protection actions (Kopyrina et al. 2023). CEPI, however, through the participation of senior officials and the support of central administrative power, can more effectively supervise and rectify local governments' environmental violations. On the other hand, there is a difference in inspection targets: CEPI shifts inspection focus from "supervising firms" to "supervising the government." Specifically, the inspection process shifts its focus from merely penalizing firms to emphasizing the accountability of local governments. It aims to compel them to enforce environmental policies and fulfill their obligations in environmental protection (Yuan et al. 2022). This transformation enhances the effectiveness of local environmental governance and boosts the commitment of local officials to adhere to their legal responsibilities in safeguarding regional ecosystems (Zhang et al. 2018; Li et al. 2023).

In summary, CEPI is an innovative solution proposed by the Chinese government to address environmental governance problems within its political decentralization. The top-down implementation approach of this policy, along with its continuous multi-phase execution, provides an ideal quasi-natural experimental setting for empirically examining the microeconomic effects of vertical supervision.

Literature review

Research on the economic consequences of CEPI. Vertical supervision is a direct oversight system by the central government over local governments, aimed at reducing deviations in implementing national policies by local authorities and ensuring policy consistency (Harris 1955). In recent years, as the drawbacks of political decentralization have become increasingly apparent, vertical supervision has gained attention and been promoted to some extent, making its economic consequences a focal point in academic research. Evidence shows that this supervision model not only mitigates agency problems in policy implementation by local governments and enhances the efficiency of public resource allocation (Besley and Coate 2003) but also curtails rent-seeking behaviors of local governments and promotes sustainable local economic development (Zhang et al. 2018). Additionally, vertical supervision has been extensively implemented across various fields, such as energy efficiency (Zhao et al. 2009), coal mine safety (Chen et al. 2015), financial services (Masciandaro and Quintyn 2016), the quality of financial information (Pan et al. 2022), and land transactions (Kong et al. 2024). These implementations underscore its vital function in minimizing information disparities between central and local authorities and alleviating regional protectionist tendencies.

The CEPI signifies a novel initiative by China to implement vertical supervision within the realm of environmental governance. Numerous prior studies have illustrated the beneficial impacts of CEPI on environmental management. For instance, it has been posited that CEPI is instrumental in advancing regional air quality, acting as a critical institutional arrangement for enhancing environmental regulatory compliance (Lin et al. 2021; Wang et al. 2021). To be specific, by implementing top-down oversight, the CEPI has enhanced environmental governance efficiency and prompted local governments to improve local legislation on environmental protection (Ding et al. 2022), accelerate regional low-carbon transitions (Razzaq et al. 2023), and increase regional total factor productivity (Zeng et al. 2023). Moreover, when faced with pressure from CEPI, local governments often pass this pressure onto firms within their jurisdiction, requiring them to adhere to stricter environmental protection standards and reduce pollutant emissions. Therefore, to meet local government environmental requirements, firms are compelled to increase environmental investment (Zeng et al. 2023; Kopyrina et al. 2023), improve production processes (Li et al. 2020), and adopt sustainable resource management practices (Wang et al. 2021).

Nevertheless, some research indicates contrasting findings. Although the enforcement of CEPI has demonstrated favorable outcomes for environmental protection in the short term, these impacts lack sustainability over extended periods (Kou et al. 2022). For instance, Yuan et al. (2022) observe that local officials would inform high-pollution firms to reduce their pollutant emissions 1 month before the CEPI but allow them to return to historical levels after the central environmental inspection team leaves. Besides concerns over the sustainability of CEPI's impact, some scholars argue that overly strict inspection regimes may compromise economic growth. For example, Lin and Sun (2023) find that local governments often respond to CEPI by directly shutting down polluting firms, which can reduce pollution levels but negatively impact local economies. Similarly, Wang et al. (2023) indicate that the pressure to comply with CEPI affects firm investment decisions, leading to decreased investment efficiency.

Research on the impact of environmental factors on labor productivity. Considering the direct influence of environmental conditions on physical health, enhancing measures for environmental protection can be regarded as an investment in human capital (Carson et al. 2011). As such, Zivin and Neidell (2012) demonstrate that ozone pollution substantially diminishes the workforce efficiency of agricultural workers in the United States. Similarly, Hanna and Oliva (2015) reveal that following the shutdown of a major refinery in Mexico City, surrounding pollution levels decreased by 19.7%, and local laborers increased their weekly working hours by 3.5%, significantly boosting labor supply. Furthermore, from the perspective of pollution duration, short-term air pollution can affect the work efficiency of some high-skilled laborers (Archsmith et al. 2018), while prolonged exposure to atmospheric pollutants may result in significant health complications, thereby impacting overall economic productivity (He et al. 2019). Additionally, environmental pollution can negatively affect employees' motivation, leading to increased "slacking off" or unproductive time (Chang et al. 2016).

From the preceding literature review, it is evident that while a considerable amount of research addresses the economic consequences of CEPI, there are no existing studies that investigate the effects of CEPI on workforce efficiency. Moreover, recent studies suggest that a good environment can enhance employees' health and productivity. However, these studies presuppose that local authorities operate independently from the environmental regulation framework, failing to account for the possible connections between institutional arrangements and environmental governance. Hence, we reexamine the economic implications of CEPI through the lens of labor productivity, aiming to uncover the complex relationships among vertical supervision, local government environmental governance, and labor productivity.

Hypothesis development

The impact of vertical supervision on labor productivity. Nations characterized by multi-tiered governance structures frequently encounter the issue of efficiently allocating responsibilities between central and local governments (Besley and Coate 2003). According to the classic decentralization theory, represented by Tiebout (1956), local governments better understand the populace's needs, thus possessing a stronger informational advantage than central governments. However, critical opinions posit that political decentralization may lack efficiency in some cases, which is detrimental to the provision of public goods (Fan et al. 2009; Jia and Nie 2017). Particularly concerning environmental governance, political decentralization is often inefficient (Kunce and Shogren 2005). On the one hand, as the agents responsible for environmental governance, local governments inevitably exhibit opportunistic tendencies due to economic development pressures. For example, Kostka et al. (2013) find that in some economically backward or resource-dependent regions, some local chiefs abuse their power of appointment and dismissal to replace environmental officials who do not align with the local economic development concept, thereby interfering with implementing central environmental policies. On the other hand, the disparity in information between central and local administrations hinders the central government's ability to comprehensively understand local environmental conditions and governance effectiveness, leading to a disconnect in policy formulation and implementation (Pan and Yao 2021). Additionally, in an effort to evade punishment from the central government, local authorities often obscure genuine environmental statistics or selectively disclose data, intensifying the level of information asymmetry.

Environmental decentralization in China represents a classic principal-agent dilemma, and CEPI, as a vertical supervision policy characterized by "supervising the government," is an effective means to alleviate this problem. In practice, local governments primarily adopt two approaches to environmental governance in reaction to the vertical supervision pressure exerted by CEPI. First, local governments increase environmental investment to address local pollution problems directly. This includes allocating substantial funds to upgrade pollution control infrastructure, accelerate the adoption of clean technologies, and enhance public consciousness regarding environmental issues (Li et al. 2020). Second, to accomplish goals in environmental governance, local governments may pressure firms by implementing stricter environmental standards, conducting regular inspections, and intensifying environmental penalties (Ding et al. 2022). Observations show that CEPI prompts firms in inspected cities to change their production methods, proactively disclose environmental data (Pan and Yao 2021), carry out green innovation (Kopyrina et al. 2023), and enhance their ESG performance (Wang et al. 2021). Hence, it is evident that under the pressure of legitimacy, local firms will actively respond to government requirements, consequently accelerating regional green transformation (Zeng et al. 2023). This is conducive to improving air quality, reducing pollution emissions, and optimizing the overall environmental condition (Lin et al. 2021; Razzaq et al. 2023).

A substantial body of evidence suggests that environmental pollution may impair worker performance by affecting respiratory, cardiovascular, and cognitive functions (Ostro 1983; Chay and Greenstone 2003; Carson et al. 2011). Therefore, improving the environment can positively impact employees' physical health, thereby enhancing labor productivity. For example, Zivin and Neidell (2012) find that when local air and water quality improves, the probability of workers being absent due to respiratory or other health issues decreases, which boosts labor supply levels. Moreover, "to be present but not working" is another important factor affecting labor productivity. Chang et al. (2019) conducted a study using data from customer service hotline operators at the Ctrip Shanghai headquarters, indicating that a better ecological environment helps increase employee job motivation, leading to improved engagement and effort in work tasks.

Furthermore, attracting talent and improving the human capital structure are important ways of enhancing labor productivity. On the one hand, high-quality talent increasingly considers environmental quality in target cities when seeking jobs (Chang et al. 2019), which suggests that urban areas with superior ecological conditions possess a greater capacity to attract such talent and consequently provide firms with higher-quality labor resources. On the other hand, environmental management and green production require firms to reshape their production processes, necessitating professional training and capability enhancement for employees and recruiting talent with relevant skills. Therefore, under the influence of CEPI, environmental improvement is more conducive for firms to attract talent and optimize the human capital structure, thus enhancing overall labor productivity.

It is noteworthy that the CEPI exhibits significant differences from other environmental policies in terms of their impact on labor productivity. First, as a top-down regulatory tool, the enforcement intensity of CEPI far surpasses that of traditional environmental policies (Kopyrina et al. 2023). Through cross-regional and cross-departmental inspection actions, CEPI effectively breaks down local protectionism, guaranteeing rigorous enforcement of environmental policies, resulting in a notable enhancement of environmental conditions in the short term (Zeng et al. 2023). This enhancement in environmental quality not only reduces the negative health impacts of environmental pollution on workers but also directly increases labor productivity by improving the working environment. In contrast, other environmental policies, such as pollution discharge fees and emission standards, often rely on the enforcement capabilities of local governments, and their effectiveness varies greatly across regions, resulting in a relatively limited boost to labor productivity. Second, the regulatory mechanism of CEPI demonstrates greater sustainability. Through regular inspections, accountability mechanisms, and public exposure, CEPI exerts long-term pressure on firms, prompting them to proactively optimize production processes and adopt clean technologies, thereby reducing pollution while enhancing production efficiency (Li et al. 2020). In contrast, other environmental policies mostly rely on economic incentives or technical standards, and firms may choose to pay fees or comply in the short term rather than fundamentally improving their production methods, thus having a weaker long-term effect on labor productivity. Third, the constraining effect of CEPI on corporate behavior is more comprehensive. It not only focuses on pollution emissions but also involves the overall environmental management capabilities of firms, including energy use efficiency and resource recycling. This comprehensive regulation can drive firms to achieve green transformation, enhancing their competitiveness while improving environmental performance, indirectly boosting labor productivity. In contrast, other environmental policies often focus on single pollutants or specific segments, providing a more limited promotion of overall production efficiency in firms. Therefore, we propose:

H1: Vertical supervision significantly improves labor productivity.

The analysis of the mechanisms through which vertical supervision affects labor productivity. Adequate willingness of local governments to address environmental problems is a prerequisite for political decentralization to achieve its governance advantages (Kunce and Shogren 2005). However, under the pressure of promotion tournaments, local officials often prioritize economic expansion and fiscal income, overlooking environmental protection (Liu and Diamond 2005). For instance, aiming to achieve rapid economic development, some local governments might attract industries with high energy consumption and allow these firms to use environmental subsidies for profit-making activities instead of green investments (Zhang et al. 2018).

The results of CEPI are linked to the performance evaluations and promotions of local officials, fundamentally alleviating the issue of insufficient willingness of local governments to participate in environmental management efforts. Specifically, China's personnel control system employs a top-down evaluation mechanism, whereby higher-level governments assess and appoint lower-level officials (Li and Zhou 2005). CEPI inspection teams, which consist of officials from the central government, are tasked with assessing the environmental performance of regional administrations and the advancement of local officials (Zeng et al. 2023). Previous research indicates that when environmental performance becomes a key criterion for official promotions, these officials place greater emphasis on green development (Li et al. 2022). Consequently, associating CEPI outcomes with the advancement of local officials effectively motivates them to focus on environmental protection, increases their commitment to environmental management, and ultimately boosts the labor productivity of local firms. Therefore, we propose:

H2: Vertical supervision improves labor productivity by enhancing the willingness of local government environmental governance.

In addition to the incentive mechanisms, the regulatory influence imposed by CEPI on local officials is crucial for strengthening the intensity of local government environmental governance. Within the existing environmental governance framework, local environmental protection agencies operate under the dual oversight of regional administrations and superior

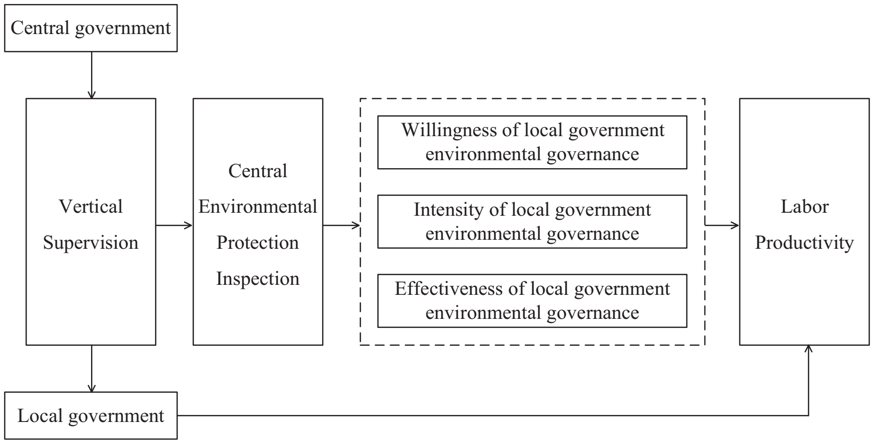

Fig. 1 Conceptual framework. This figure shows the conceptual framework diagram of this study based on the theoretical analysis. Source: Author construction.

departments. Furthermore, superior departments mainly provide operational guidance, whereas local governments retain key authorities, such as personnel appointments and budget allocations (Mol and Carter 2006). In this context, local governments focused on economic growth maintain substantial intervention capabilities over actual environmental governance practices, thereby weakening the autonomy of local environmental protection agencies in implementing regulatory actions. To address these issues, the vertical supervision mechanism of CEPI enables it to bypass local government and directly evaluate the performance of grassroots environmental protection departments (Li et al. 2023). This centralized oversight by the central government reduces the political intervention of regional administrations in environmental protection, strengthening grassroots environmental departments' enforcement efforts. Consequently, the increased intensity of environmental governance compels firms to invest more in environmental protection, improve production processes, and gradually optimize human capital structure, thereby increasing labor productivity. Therefore, we propose:

H3: Vertical supervision improves labor productivity by strengthening the intensity of local government environmental governance.

Although China has implemented a range of environmental policies in recent years, the effectiveness of its environmental governance has faced criticism. Some local governments exhibit formalism in their governance practices, resulting in recurring environmental issues and difficulty establishing long-term effective governance mechanisms (Kou et al. 2022; Yuan et al. 2022). The adoption of CEPI has effectively mitigated this limitation. On the one hand, CEPI generates powerful public pressure by exposing environmental violations and local government negligence. This exposure mechanism raises public awareness of environmental protection and enhances local governments' focus on environmental concerns, gradually fostering a long-term environmental protection atmosphere maintained by both government and citizens (Li et al. 2020). On the other hand, the inspection team will generate rectification reports, requiring local governments to formulate and implement rectification plans within a specified period. For regions with insufficient rectification efforts, CEPI conducts "look-back" inspections to ensure that environmental issues are effectively resolved (Ding et al. 2022). The continuous follow-up inspection mechanism guarantees the effectiveness of environmental governance measures, fostering a sustainable and resilient ecosystem (Jia and Chen 2019). As the effectiveness of environmental governance improves, regional ecological environments are significantly enhanced, reducing productivity losses due to sick leave and contributing to an overall increase in labor productivity. Therefore, we propose:

H4: Vertical supervision improves labor productivity by enhancing the effectiveness of local government environmental governance.

Drawing from the theoretical analysis presented earlier, Fig. 1 illustrates the conceptual framework diagram.

Model design

Sample and data. Following the existing literature (Li et al. 2023), to minimize the COVID-19 pandemic-related distortions in the labor market and commercial activities, our analysis designated 2019 as the final year, establishing a study window spanning 4 years prior to and following CEPI's implementation. Based on this, our initial sample covered China's A-share listed companies over an 8-year period (2012–2019). Financial indicators were obtained from the CSMAR database, while the employee data was derived from the WIND database. We obtained regional economic indicators from various provinces and cities from the China Statistical Yearbook. In alignment with earlier research (Kopyrina et al. 2023; Li et al. 2023), this study implemented the following steps: excluding firms (1) operating in financial-related sectors, (2) designated as special treatment (ST, *ST), and (3) lacking complete financial data. Our final sample consisted of 3419 unique firms and 20,848 firm-year observations.

Variable definition

Dependent variable. Referring to Shi et al. (2020), labor productivity was measured by dividing total operating revenue by the number of employees. To mitigate heteroskedasticity effects in our econometric analysis, we subsequently took the natural logarithm of the ratio (*LP*).

Core independent variable. The inspection team conducted staggered deployments across multiple provincial jurisdictions throughout the evaluation period, ensuring comprehensive coverage and effective monitoring. Consistent with Pan and Yao (2021), Kopyrina et al. (2023), and Li et al. (2023), CEPI was defined as a dummy variable indicating whether the inspection team had entered the province of a listed firm's location during the year. It is the interaction term between the treatment group visited by the inspection team during the sample period (*Treat*) and year dummy variables for different times the inspection team

Table 2 Descriptive statistics and correlation matrix.

Variables	Mean	S.D.	Median	1	2	3	4	5
1. LP	13.790	0.851	13.700					
2. CEPI	0.521	0.500	1.000	0.132***				
3. Age	2.165	0.794	2.303	0.221***	0.030***			
4. Size	7.685	1.244	7.610	−0.087***	0.012*	0.249***		
5. Roa	0.035	0.061	0.035	0.060***	−0.003	−0.197***	0.057***	
6. Lev	0.426	0.207	0.417	0.319***	−0.023***	0.371***	0.351***	−0.360***
7. Growth	0.172	0.422	0.100	0.118***	0.052***	−0.055***	−0.002	0.196***
8. Capin	2.594	2.212	1.971	−0.158***	−0.004	0.130***	−0.331***	−0.179***
9. Dual	0.274	0.446	0.000	−0.094***	0.050***	−0.230***	−0.129***	0.032***
10. Board	2.128	0.199	2.197	0.055***	−0.083***	0.157***	0.259***	0.013*
11. GDP	0.095	0.322	0.089	0.011	0.025***	0.006	−0.013*	0.009
12. Structure	0.412	0.095	0.440	−0.172***	−0.322***	−0.061***	−0.002	0.010
13. ENV	0.030	0.010	0.028	0.063***	0.254***	0.015**	0.059***	−0.017**
Variables	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
7. Growth	0.021***							
8. Capin	−0.011	−0.078***						
9. Dual	−0.128***	0.030***	−0.011					
10. Board	0.153***	−0.029***	−0.025***	−0.179***				
11. GDP	−0.002	0.008	−0.004	0.022***	−0.003			
12. Structure	−0.011	−0.037***	−0.095***	0.000	0.030***	0.000		
13. ENV	0.018***	0.012*	0.038***	−0.001	−0.006	−0.008	−0.482***	

This table presents descriptive statistics and the correlation matrix of the main variables used in the analysis. All the continuous variables are winsorized at the 1% and 99% levels.
*, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

enters (*Post*). Specifically, *Treat* equals 1 if the province where a firm is located has been visited by the inspection team during the sample period. *Post* presents a time dummy variable that equals 1 from the year the inspection team is stationed in the province. Overall, *CEPI* equals 1 for the current and subsequent years when the inspection team was stationed in the province where the firm is located and 0 otherwise.

Control variables. Referring to Shi et al. (2020) and Li et al. (2023), we controlled for several firm-level and region-level characteristics. Specifically, we included firm size (*Size*), leverage (*Lev*), firm age (*Age*), capital intensity (*Capin*), operating revenue growth rate (*Growth*), return on total assets (*Roa*), CEO duality (*Dual*), board size (*Board*), economic growth (*GDP*), industry structure (*Structure*) and environmental protection intensity (*ENV*) in the model. For specific variable definitions, see Table A1.

Research design. We constructed a staggered difference-in-difference (DID) model to examine the impact of vertical supervision on labor productivity.

$$LP_{i,t} = \alpha_0 + \alpha_1 CEPI_{i,t} + \sum \alpha Control_{i,t} + u_i + v_t + w_i + z_i + \varepsilon_{i,t} \quad (1)$$

In Eq. (1), $LP_{i,t}$ denotes the labor productivity of firm i at year t. The core independent variable $CEPI_{i,t}$ is a dummy variable that equals 1 for province-year observations following the inspections in a given year and 0 otherwise. It is the interaction term between the treatment group ($Treat_i$) and year dummy variables ($Post_t$). Due to multicollinearity, the coefficients of $Treat_t$ and $Post_t$ are absorbed by the firm and year fixed effects, respectively. Therefore, the individual terms $Treat_t$ and $Post_t$ are omitted in the model.

$Control_{i,t}$ denotes a set of control variables at both the firm and regional levels. α_t signifies a constant term. u_i, v_t, w_i, z_i, correspond to firm, year, province, and industry fixed effects, respectively. $\varepsilon_{i,t}$ represents random error. To mitigate potential bias caused by outliers, all continuous variables were winsorized at the 1st and 99th percentiles of their distributions. Furthermore, robust standard errors were clustered at the firm level.

Research results

Descriptive statistics. Table 2 displays the descriptive statistics and correlation matrix for the key variables. The mean of labor productivity (*LP*) is 13.790, the median is 13.700, and the standard deviation is 0.851, indicating labor productivity varied considerably among different firms in our sample. The mean value of the core independent variable (*CEPI*) is 0.521, suggesting that around 52.1% of the sample was supervised by the central inspection team throughout the sample period.

Moreover, Table 2 reveals a significantly positive association between CEPI implementation and labor productivity, preliminarily suggesting that vertical supervision from the central government can significantly promote labor productivity. The correlation coefficients among other variables remain below the 0.5 threshold, alleviating potential multicollinearity issues in our regression analyses.

Baseline results. Table 3 presents the baseline results. Both Columns (1) and (3) incorporate year, industry, and province fixed effects, with Column (3) extending to include control variables. The coefficients of the *CEPI* are 0.040 and 0.031, respectively, and are significant at the 5% level. Considering the potential bias from unobservable factors varying across time at the industry levels, Column (2) additionally controls for year × industry fixed effects. The results show that the coefficient of *CEPI* remains significantly positive at the 5% level. Column (4) advances the analysis by incorporating firm fixed effects, revealing a CEPI coefficient of 0.029, significant at the 1% level. These regression results demonstrate that vertical supervision effectively increases labor productivity, supporting Hypothesis 1.

Robustness tests

Parallel trend test. To ensure the validity of the DID model, it is crucial to confirm that the control and treatment groups demonstrate parallel trends in labor productivity prior to the

Table 3 Benchmark regression results.

Variables	(1) LP	(2) LP	(3) LP	(4) LP
CEPI	0.040** (2.40)	0.030** (2.29)	0.031** (2.30)	0.029*** (2.94)
Age		0.150*** (11.27)	0.150*** (11.27)	0.124*** (5.78)
Size		−0.232*** (−19.84)	−0.232*** (−19.83)	−0.424*** (−20.52)
Roa		2.392*** (17.48)	2.392*** (17.48)	1.267*** (14.72)
Lev		1.193*** (18.77)	1.193*** (18.76)	0.706*** (11.49)
Growth		0.107*** (7.96)	0.107*** (7.94)	0.149*** (15.86)
Capin		−0.123*** (−21.45)	−0.123*** (−21.39)	−0.137*** (−25.80)
Dual		−0.066*** (−3.70)	−0.065*** (−3.69)	−0.005 (−0.35)
Board		0.208*** (4.38)	0.208*** (4.37)	0.196*** (4.61)
GDP		0.000 (0.03)	0.000 (0.03)	0.009 (1.09)
Structure		−0.361 (−1.39)	−0.357 (−1.38)	−1.155*** (−4.17)
ENV		−0.172 (−0.29)	−0.174 (−0.29)	0.959* (1.69)
Constant	13.760*** (76.26)	14.671*** (91.20)	14.590*** (69.80)	16.583*** (85.01)
Year FE	Yes	No	Yes	Yes
Industry FE	Yes	No	Yes	No
Province FE	Yes	Yes	Yes	No
Firm FE	No	No	No	Yes
Year × Industry FE	No	Yes	No	No
Observations	20,848	20,848	20,848	20,848
Adj R^2	0.348	0.512	0.513	0.521

T values are reported in parentheses.
Coefficients marked with *, **, and *** are significant at 10%, 5%, and 1%, respectively.

Table 4 Robustness tests: parallel trend tests.

Variables	Dependent variable: LP	
	Coefficients	*T*-value
Pre4	−0.077	−1.46
Pre3	−0.047	−1.24
Pre2	−0.022	−1.06
Current	0.050**	2.20
Post1	0.148***	3.21
Post2	0.224***	3.17
Post3	0.301***	3.18
Constant	16.473***	85.14
Controls	Yes	
Year FE	Yes	
Firm FE	Yes	
Observations	20,848	
Adj R^2	0.470	

Coefficients marked with **, and *** are significant at 5%, and 1%, respectively.

introduction of CEPI. We constructed Eq. (2) to conduct a parallel trend test.

$$LP_{i,t} = \alpha_0 + \alpha_1 Pre4_{i,t} + \alpha_2 Pre3_{i,t} + \alpha_3 Pre2_{i,t} + \alpha_4 Current_{i,t} + \alpha_5 After1_{i,t} + \alpha_6 After2_{i,t} + \alpha_7 After3_{i,t} + \sum \alpha Control_{i,t} + u_i + v_t + \varepsilon_{i,t} \quad (2)$$

For the samples in the years before (after) the presence of the inspection team, the values of *Pre1-Pre4* (*After1-After3*) are equal to 1 and 0 otherwise. For the samples in the year the environmental inspection teams were present, *Current* takes the value of 1 and 0 otherwise. We remove *Pre1* from the model to avoid interference from multicollinearity. The results of the parallel trend tests are detailed in Table 4, with the trend of regression coefficients and their 95% confidence intervals depicted in Fig. 2. The coefficients of *Pre2-Pre4* are not statistically significant before the CEPI implementation, affirming the parallel trends assumption. Meanwhile, the coefficients of *Current* and *After1-After3* are significantly positive, with values progressively increasing, indicating that the CEPI has maintained its effectiveness over time.

Placebo test. Our study is subject to potential unobservable confounding variables and measurement errors. Therefore, we allocated firms in the sample to the treatment group through random assignment and performed the baseline regression. This procedure was repeated 1000 times to enhance the robustness and credibility of our examination. Figure 3 illustrates the density distribution of the coefficients for the core independent variable (*CEPI*). The findings demonstrate that the coefficients for the randomly assigned treatment group concentrate near 0 and are markedly distinct from the actual coefficients, confirming the robustness of our results.

Robust staggered DID tests. In settings with staggered treatment timing and varying intensities, traditional DID methods may yield biased average treatment effect estimates (De Chaisemartin and d'Haultfoeuille 2020; Callaway and Sant'Anna 2021). Following Bareille et al. (2023) and Gong et al. (2023), we employed three approaches: the bias-corrected method (De Chaisemartin and d'Haultfoeuille 2020), which uses stable treatment groups to infer trends for dynamic treatment groups; the doubly robust inverse probability-weighted DID method (Callaway and Sant'Anna 2021), which calculates weighted estimating functions using untreated units; and an imputation-based DID method, leveraging pre-treatment data from untreated groups to estimate potential outcomes. As shown in Table 5, the results align with our primary findings, confirming the significant impact of vertical supervision on labor productivity.

Propensity score matching method. If the pre-treatment characteristics between the treatment and control groups are not comparable, selection bias may exist, which could affect the validity of the results (Kopyrina et al. 2023). Based on this, we employed the propensity score matching (PSM) method to

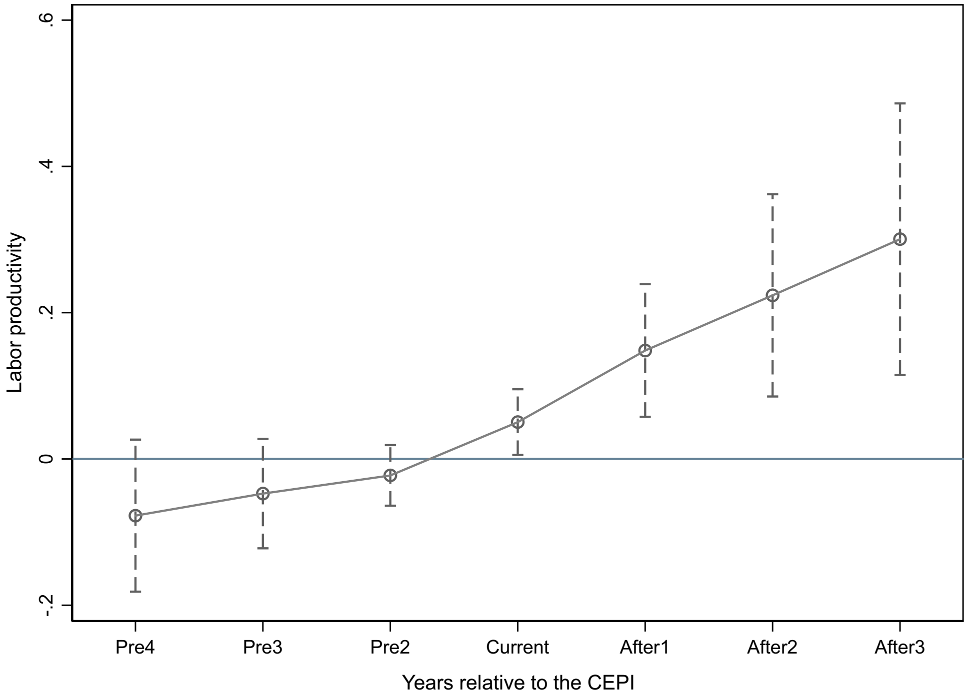

Fig. 2 Parallel trend tests for CEPI on labor productivity. This figure displays the results of parallel trend tests for the impact of CEPI on labor productivity over time. The figure shows the estimated effects of CEPI on labor productivity before and after the implementation of the program, providing evidence of parallel trends in the pre-treatment period. Source: Author construction.

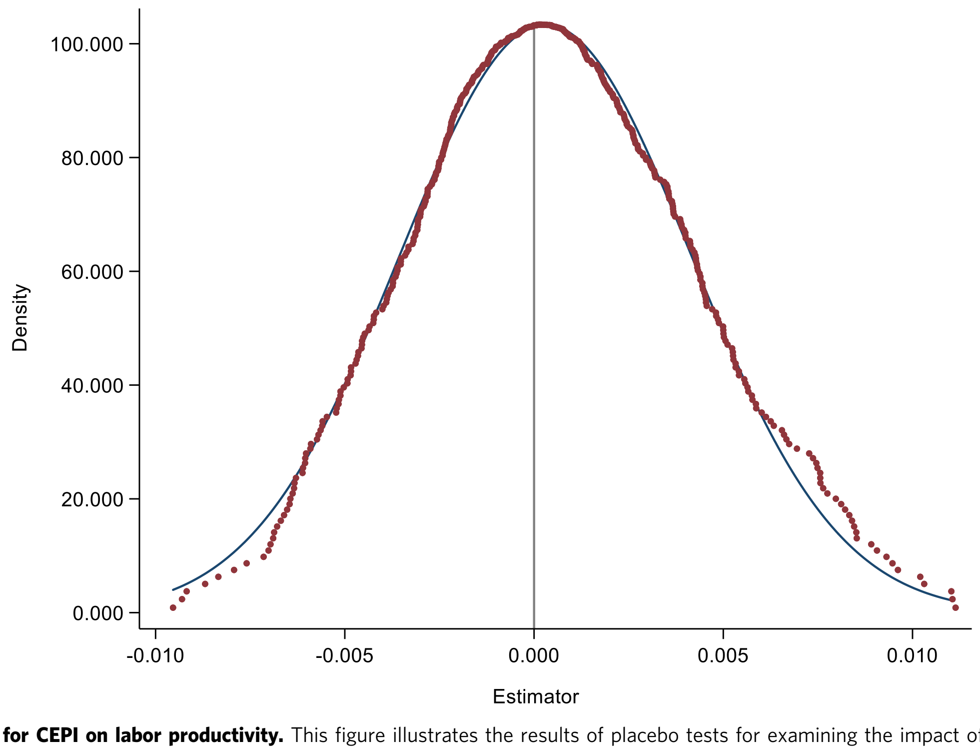

Fig. 3 Placebo tests for CEPI on labor productivity. This figure illustrates the results of placebo tests for examining the impact of CEPI on labor productivity. The placebo tests involve analyzing the effects of CEPI at different time points, providing a basis for evaluating the causal impact of the program on labor productivity. Source: Author construction.

examine the impact of vertical supervision on labor productivity. We calculated propensity scores using a logit model and executed a 1:1 nearest neighbor matching procedure with covariates, including all control variables from Eq. (1). Using the sample after PSM, we performed the staggered DID regression, with the results shown in Column (1) of Table 6. The coefficient of *CEPI* is 0.034, statistically significant at the 5% level, indicating that our regression results still hold after controlling for sample selection bias.

Entropy balancing method. Due to the substantial loss of samples when using the PSM method, we referred to Hainmueller's (2012)

Table 5 Robust staggered DID estimates.

Panel A: De Chaisemartin and d'Haultfoeuille's (2020) method	
Dependent Variable	LP
CEPI	0.026**
	(2.36)
Controls	Yes
Panel B: Callaway and Sant'Anna's (2021) method	
Dependent Variable	LP
CEPI	0.340**
	(2.05)
Controls	Yes
Panel C: Borusyak's (2024) method	
Dependent Variable	LP
CEPI	0.059***
	(4.55)
Controls	Yes

T values are reported in parentheses.
Coefficients marked with **, and *** are significant at 5%, and 1%, respectively.

Table 6 Robustness tests: propensity score matching and entropy balancing analysis.

Variables	(1) PSM LP	(2) Entropy balancing LP
CEPI	0.034** (2.57)	0.026** (2.53)
Constant	16.877*** (68.37)	16.752*** (86.07)
Controls	Yes	Yes
Year FE	Yes	Yes
Firm FE	Yes	Yes
Observations	11,454	20,848
Adj R^2	0.541	0.422

T values are reported in parentheses.
Coefficients marked with **, and *** are significant at 5%, and 1%, respectively.

research and utilized entropy balancing to match the treatment and control groups without losing samples. Entropy balancing achieves a basic balance between the treatment and control groups in terms of mean, variance, and skewness by assigning different weights to the control group samples, mitigating the impact of intergroup differences on the results. Column (2) of Table 6 shows that the coefficient of *CEPI* remains significantly positive, confirming that the main conclusion is robust.

Change the measurement of labor productivity. In the main regression, labor productivity was measured as operating revenue per employee. To mitigate the influence of non-operating revenue, we alternatively defined the dependent variable (*LP_Alter1*) as (total operating revenue minus non-operating revenue) divided by the number of employees. Additionally, following Sánchez and Benito-Hernández (2015), we used total production per employee (*LP_Alter2*), calculated as total sales plus inventory changes, as another measure. As shown in Columns (1) and (2) of Table 7, the positive effect of CEPI on labor productivity remains consistent with the main findings.

Change the definition of the treatment group variable. The magnitude of the treatment effect may vary depending on the timing of environmental inspections conducted by the inspection group throughout the year. Therefore, we redefined the treatment group variable using the following two approaches. First, if the inspection teams were stationed in the provinces after June of the

Table 7 Other robustness tests.

Variables	(1) LP_Alter1	(2) LP_Alter2	(3) LP	(4) LP	(5) LP	(6) LP	(7) LP	(8) LP	(9) LP	(10) LP	(11) LP
CEPI	0.027***	0.023**	0.030***	0.042***	0.028***	0.029***	0.028***	0.028***	0.039***	0.028**	0.024**
	(2.76)	(2.06)	(2.88)	(3.48)	(2.89)	(2.94)	(2.94)	(2.89)	(3.48)	(2.28)	(2.49)
Reduce					0.157**			0.157**			
					(2.09)			(2.09)			
Newlegal						0.379***		0.371***			
						(10.24)		(9.95)			
Judiciary							0.015	0.015			
							(1.13)	(1.14)			
Constant	16.573***	16.282***	16.594***	16.588***	16.577***	16.583***	16.571***	16.564***	16.711***	16.431***	16.581***
	(82.73)	(78.20)	(84.88)	(85.10)	(85.13)	(85.01)	(84.76)	(84.87)	(71.40)	(65.16)	(79.49)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	20,746	20,631	20,848	20,848	20,848	20,848	20,848	20,848	14,408	8558	19,629
Adj R^2	0.523	0.421	0.521	0.521	0.522	0.521	0.521	0.521	0.515	0.505	0.511

T values are reported in parentheses.
Coefficients marked with **, and *** are significant at 5%, and 1%, respectively.

Table 8 Mechanism analysis.

Variables	(1) ER	(2) LP	(3) Fines	(4) LP	(5) AQI	(6) LP	(7) PM	(8) LP
CEPI	0.092*** (16.08)	0.026*** (2.60)	0.192** (2.37)	0.029*** (2.90)	−2.602*** (−10.14)	0.022** (2.41)	−2.540*** (−11.30)	0.022** (2.37)
ER		0.044** (2.36)						
Fines				0.004** (2.10)				
AQI						−0.001** (−2.17)		
PM								−0.001** (−2.28)
Constant	0.947*** (14.88)	16.516*** (83.79)	0.086 (0.35)	16.622*** (81.03)	97.289*** (19.98)	16.761*** (83.78)	67.729*** (16.65)	16.746*** (83.91)
Sobel *Z*	8.889***		6.261***		8.180***		7.714***	
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	20,545	20,545	19,888	19,888	18,772	18,772	18,772	18,772
Adj R^2	0.380	0.521	0.189	0.520	0.838	0.530	0.857	0.546

T values are reported in parentheses.
Coefficients marked with **, and *** are significant at 5%, and 1%, respectively.

current year, these samples are considered to be affected by the CEPI starting from the following year. Table 7 Column (3) shows that the coefficient of *CEPI* is 0.030, significant at the 1% level. Second, the samples where environmental inspections were implemented after November of the current year are considered to be impacted by the CEPI starting from the following year. From the results of Table 7 Column (4), our main conclusions still hold.

Exclude the effects of contemporary policies. The impact of CEPI on labor productivity can be influenced by policies implemented during the same period. First, the policy implemented in 2016 to reduce production capacity aims to eliminate inefficient and unproductive firms, leading to a consolidation of resources and increased productivity among the remaining firms. Second, the newly enacted "Environmental Protection Law" in 2015 significantly improved and updated China's legal framework for environmental protection, which may influence the effect of the CEPI. Third, the establishment of China's environmental courts has significantly limited firms' pollution behaviors by enhancing regional environmental enforcement capacity (Zhang et al. 2019), which in turn affects labor productivity.

Therefore, we introduced dummy variables for different policies to control for the potential interference of these policy implementations on the impact of CEPI. Specifically, we set a dummy variable, *Reduce*, based on the list of key industries for capacity reduction released by the State Council of China in 2016. *Reduce* equals 1 if the sample belongs to the six key industries of steel, coal, cement, shipbuilding, electrolytic aluminum, and glass, and 0 otherwise. Additionally, considering the enactment of the new "Environmental Protection Law" in 2015, the *Newlegal* equals 1 for samples from 2015 to 2019 and 0 for other years. Furthermore, the *Judiciary* equals 1 for observations in the years after the city established an environmental court and 0 otherwise. As shown in Columns (5)–(7) of Table 7, we find that after controlling for the policies above, the coefficient of *CEPI* remains significantly positive. In Column (8) of Table 7, we simultaneously control these three policies in the regression model and find that the relationship between *CEPI* and *LP* remains consistent with baseline results.

Exclude the effects of other factors

Exclude the effects of "look-back" inspection: Starting in May 2018, the inspection teams conducted "look-back" inspections in 20 provinces. To avoid the cumulative impact of "look-back," we excluded the samples after 2018. In Column (9) of Table 7, the coefficient of *CEPI* is still significantly positive. Additionally, we excluded samples from provinces that experienced environmental inspection "look-back" in 2018 for analysis in Column (10). We continue to find a positive and statistically significant effect of CEPI on labor productivity.

Exclude the effects of changes in firm location: The observed variation in labor productivity between different samples could potentially be attributed to changes in operating location. We further excluded samples that experienced changes in their operating locations during the sample period. As is shown in Column (11) Table 7, the coefficient of *CEPI* remains statistically significant, consistent with our main results.

Mechanism analysis. The above empirical results have confirmed the promoting effect of CEPI on labor productivity. This section systematically investigates the underlying mechanisms through which CEPI influences productivity from three aspects.

Enhancing the willingness of local government environmental governance. The frequency of environmental keywords in local government annual work reports serves as a proxy for their environmental protection commitment (Chen et al. 2018). Following Chen et al. (2018) and Tu et al. (2024), we extracted environment-related text from provincial government work reports, counted the frequency of environmental keywords, and calculated the ratio of environment-related words (*ER*) to measure local governments' environmental governance willingness. An increased *ER* ratio reflects stronger municipal commitment to environmental governance. Column (1) of Table 8 shows that the coefficient of *ER* is 0.092, significant at the 1% level, indicating that CEPI implementation has enhanced local governments' environmental governance willingness. Column (2) reveals significantly positive coefficients for both *CEPI* and *ER*, with a Sobel

Table 9 Heterogeneity analysis.

Variables	(1) SOE	(2) Private firm	(3) Higher share of secondary sector output	(4) Lower share of secondary sector output	(5) More environmental regulations	(6) Less environmental regulations
	LP	LP	LP	LP	LP	LP
CEPI	0.044*** (2.82)	0.009 (0.70)	−0.005 (−0.37)	0.093*** (5.05)	0.052*** (3.93)	0.015 (0.97)
Constant	16.602*** (41.21)	16.351*** (73.84)	16.034*** (61.60)	16.576*** (61.17)	17.097*** (55.91)	15.967*** (73.46)
P value for the test of the difference	0.036**		0.000***		0.000***	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7625	11,576	9495	11,353	10,052	10,796
Adj R^2	0.523	0.534	0.534	0.519	0.552	0.506

T values are reported in parentheses.
Coefficients marked with **, and *** are significant at 5%, and 1%, respectively.

test *z* value of 8.889 (significant at the 1% level). These results suggest that CEPI boosts labor productivity by strengthening local governments' environmental governance commitment, supporting Hypothesis 2.

Strengthening the intensity of local government environmental governance. Referring to Shimshack and Ward (2005), we measured the intensity of local government environmental governance through population-adjusted aggregate fines in environmental penalty cases (*Fines*). An increase in the adjusted amount of environmental fines signifies a more rigorous enforcement effort by local governments. The results in Column (3) of Table 8 demonstrate a substantial positive relationship between CEPI and the total fines in environmental penalty cases. In Column (4), the coefficients of *CEPI* and *Fines* are both significantly positive, and the *z* value of the Sobel test is significant at the 1% level. These findings indicate that implementing CEPI promotes labor productivity by strengthening the intensity of local government environmental governance. Therefore, Hypothesis 3 is supported.

Increasing the effectiveness of local government environmental governance. Regional air quality directly reflects environmental governance effectiveness. Referring to Jia and Chen (2019), we measured air quality using each province's average annual AQI index and PM2.5 concentration. Higher AQI and PM2.5 levels indicate poorer regional air quality. Columns (5) and (7) of Table 8 show a significantly negative effect of CEPI on air quality. In Columns (6) and (8), after incorporating the mediating variable, the coefficient of CEPI becomes significantly positive at the 1% level, while the coefficients of AQI and PM2.5 remain significantly negative. The Sobel test *z* value is also significant at the 1% level. These findings suggest that CEPI enhances labor productivity by improving the effectiveness of local government environmental governance, thereby validating Hypothesis 4.

Heterogeneity analysis

The impact of property rights nature. SOEs function as dual roles within regional economies, simultaneously acting as a primary source of local government revenue while maintaining a key provider of employment. Therefore, compared to private enterprises, local governments have strong incentives to protect SOEs by relaxing environmental enforcement, delaying rectification requirements, and offering policy incentives to reduce environmental pressure on SOEs (Zhang et al. 2019). The implementation of CEPI has elevated environmental oversight from the local to the central level, directly weakening local governments' ability to shield SOEs, thus making the impact of vertical supervision on SOEs more significant compared to private enterprises.

We divided the sample into SOEs and private enterprises and performed regressions for each subsample. The results in Columns (1) and (2) of Table 9 indicate that for the SOE sample, the coefficient of *CEPI* is 0.044 and is significant at the 1% level. However, for the private enterprise sample, the coefficient of *CEPI* is not statistically significant. The intergroup difference test reveals that the coefficients between these two groups exhibit a statistically significant difference. These regression results indicate that vertical supervision has a stronger positive effect on the labor productivity of SOEs compared to private enterprises.

The impact of regional resource dependency. Regions with low resource dependence tend to focus on high-value-added industries, which consume fewer resources. Therefore, when facing CEPI, their production models are more flexible and can be quickly adjusted to meet environmental regulatory requirements. In contrast, regions with high resource dependence face greater challenges in adapting to vertical supervision due to their economies' heavy reliance on resource-based industries. For these regions, the cost of adjusting production processes is higher (Razzaq et al. 2023). Consequently, we predict that vertical supervision will more effectively promote production improvements in regions with lower resource dependence, thereby having a more significant impact on labor productivity.

Following Yang et al. (2022), we measured the degree of resource dependence in each region using the ratio of secondary industry output to GDP. The higher the ratio, the more dependent the area is on resources for its development. We used the median level of this variable from the year prior to the implementation of the CEPI (i.e., 2015) as the grouping criterion. This approach ensures the exogeneity of group classification and enhances the validity of causal inference (Xu et al. 2021; Liu 2023). Utilizing the 2015 median value of this indicator, we divided the sample into two groups characterized by different degrees of resource dependence. The results in Columns (3) and (4) of Table 9 show that the coefficient of *CEPI* demonstrates statistical significance exclusively within the group exhibiting a lower share of secondary sector output. The intergroup difference test reveals that the coefficients between these two groups exhibit a statistically significant difference. These results indicate that the positive impact of vertical supervision on labor productivity is more pronounced in regions with lower resource dependence.

The impact of environmental legislation systems. For vertical supervision to play a role in environmental governance, it must be based on a comprehensive environmental legislation system (Ding et al. 2022). A comprehensive legislative system can provide a clear legal framework and enforcement standards for vertical supervision, thereby increasing the pressure on firms to comply with environmental regulations. Therefore, we predict that the impact of vertical supervision on labor productivity will be more significant in areas where the environmental legislation system is more complete.

Following Zhang et al. (2019), we measured the completeness of the environmental legislation system using the number of effective environmental regulations in each province. The sample was divided into two sub-samples based on the 2015 median of this value, and separate regressions were conducted. As shown in Columns (5) and (6) of Table 9, the coefficient of *CEPI* is significant only in the group with more environmental regulations, and the difference between the coefficients of the two groups is statistically significant. These results indicate that the positive effect of vertical supervision on labor productivity is stronger in regions with a more comprehensive environmental legislation system.

Discussion and conclusion

Concluding remarks. This study leverages the CEPI as an exogenous shock, applying a staggered DID approach to evaluate the impact of vertical supervision on labor productivity. The conclusions obtained are as follows: First, labor productivity significantly improved after the CEPI implementation, suggesting that vertical supervision significantly enhances labor productivity. The conclusion remains after conducting some robustness tests. Second, mechanism analysis shows that the CEPI affects labor productivity through three potential channels: enhancing local governments' willingness for environmental governance, increasing their governance efforts, and improving the overall effectiveness of environmental governance. Finally, the influence of vertical supervision on labor productivity differs across firms and regions. This positive impact is more evident in SOEs, regions with lower resource reliance, and regions with stronger environmental regulation.

Policy implications. First, our research indicates that the CEPI significantly enhances labor productivity. The central government should increase the frequency and scope of vertical supervision while continuously innovating the vertical regulatory model to organically combine authority and sustainability, thus achieving both environmental protection and economic development. Second, the impact of vertical supervision on labor productivity differs by context, with a more positive effect observed in SOEs. Therefore, the central government should increase financial support and policy guidance for private firms while strengthening environmental supervision. Furthermore, vertical supervision proves more effective in regions with lower resource dependence and better environmental legislation systems. Consequently, local governments should innovate economic development models to reduce their reliance on natural resources. Additionally, apart from CEPI implementation, it is essential for relevant authorities to further enhance the framework and completeness of environmental legislation to create a conducive legal environment for proactive vertical supervision.

Future research recommendations. Although our research helps optimize vertical supervision policies and enhance economic efficiency, some limitations remain. Due to data availability constraints, this study focuses solely on listed Chinese firms. Subsequent investigations may extend the scope of our empirical evidence by incorporating comprehensive field studies and systematic survey methodologies to examine how vertical supervision affects the labor productivity of non-listed firms.

Data availability

Data generated during this analysis are provided as Supplementary Materials.

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Author contributions
Weimin Xie contributed to the conceptualization, methodology, and formal analysis of the research, as well as played a significant role in writing and revising the manuscript. Jialu Guo was involved in the project design and development of the research framework and provided critical insights during the data analysis and interpretation phase, contributing to manuscript editing. Hengxin Zhang assisted in the data analysis and visualization and contributed to the drafting, review, and editing of the manuscript. Mingxiao Fang was primarily responsible for data collection, ensuring the integrity and accuracy of the data, and also contributed to the initial data analysis.

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The authors declare no competing interests.

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