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Research article

Air pollution control or economic development? Empirical evidence from enterprises with production restrictions

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ABSTRACT

Production restriction is an environmental regulation adopted in China to curb the air pollution of industrial enterprises. Frequent production restrictions may cause economic losses for enterprises and further hinder their green transformation. Polluting enterprises are faced with the dilemma of choosing environmental protection or economic development. Using panel data on industrial enterprises in China from 2016 to 2019, this paper evaluates the impact of production restrictions on both enterprises' environmental and economic performance with regression models. The results show that production restrictions significantly drop the concentrations of SO2 and NOx emitted from polluting enterprises. Meanwhile, production restrictions have significant negative effects on operating income, financial expenses, net profit, and environmental protection investment. The mechanism analysis reveals that production restrictions mitigate air pollutant concentrations by increasing the number of green patents and improving total factor productivity, which also verifies the Porter hypothesis. However, there is a masking mediating effect of environmental investment, which indicates that the reduction of environmental investment hinders the enterprise's efforts to control air pollution. In addition, heterogeneous analysis shows that the economic shock on microenterprises is larger than that on small enterprises. Implementing production restrictions for microenterprises may be a way to eliminate their backwards production capacity.

1. Introduction

Rapid and intensive economic growth brings a series of environmental issues, such as climate change and air pollution (Sheehan et al., 2014; Simionescu et al., 2022). In particular, developing countries, such as China, face severe air pollution problems. The Chinese government has implemented positive and stringent regulations to control air pollution by abandoning the traditional economic growth path and exploring new development pathways to reconcile economic and environmental goals (Han et al., 2021; Wang et al., 2022). However, balancing economic growth and environmental governance is a major challenge not only for China, but also for counties striving to achieve sustainable economic development.

In reality, environmental governance may be a double-edged sword for economic development. There are various perspectives regarding the impacts of environmental regulation on economic performance. On the one hand, neoclassical economics believes that environmental policies increase private production costs and reduce the competitiveness of enterprises (Illge and Schwarze, 2009). The change in costs would offset the positive effects of environmental protection on society and produce negative effects on economic growth (Annicchiarico and Di Dio, 2015; Zhang et al., 2021b). On the other hand, Porter and Linde (1995) believed that environmental protection and economic development are not controversial. The Porter hypothesis states that reasonable environmental regulation could encourage enterprises to carry out more innovative activities and improve their productivity, which offsets the

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costs brought by environmental protection and improves the profitability of enterprises in the market (Porter, 1991; Porter and Linde, 1995).

Previous empirical studies have paid more attention to the impacts of environmental regulations on air pollution reduction in different sectors at the national or city level. For example, studies find that driving restriction (Han et al., 2020; Viard and Fu, 2015), retirement of inefficient vehicles (Alberini et al., 2018), and stringent fuel standards (Li et al., 2020) are effective measures for the reduction of air pollution from the urban transport sector. For the residential sector, clean heating (Barrington-Leigh et al., 2019; Du et al., 2018; Feng et al., 2021a) and bans on small coal-fired boilers (Deng et al., 2021) have significant reduction effects on the concentrations of $PM_{2.5}$, PM_{10}, and SO_2. In addition, environmental tax (Li et al., 2021, 2022), phasing out outdated industrial capacities (Zhang et al., 2019), and stringent industrial emission standards (KarplusValerie et al., 2018) have effects on improving air quality and decreasing the concentrations of air pollutants for the industrial sector.

Due to data limitations, only some researchers focus on the impacts of policies on air pollution reduction at the enterprise level. Additionally, more studies are needed to provide empirical evidence on the impacts of environmental regulation on enterprises' economic performance. The mechanism of environmental regulation acting on an enterprise's economic performance and then reacting to air pollution reduction also needs to be clarified. Thus, this paper identifies the impacts of a typical environmental regulation, i.e., a production restriction policy, on industrial enterprises' economic and environmental performance. Potential mediating effects are also analysed.

Air quality improvements contributed by environmental regulations also bring health co-benefits for the public (Barrington-Leigh et al., 2019; Li et al., 2018; Zhang et al., 2019). Scholars have paid more attention to the health-economic co-benefits of environmental policies, and cost−benefit analysis has been considered a necessary part of the evaluation framework of environmental policies (Scovronick et al., 2019; Vandyck et al., 2018). For example, if the United States implements the clean transportation policy, 14,000 premature deaths will be reduced by 2030 due to the improvement of air quality; if the clean energy policy is implemented, 175000 premature deaths will be avoided, and short-term health co-benefits will amount to $250 billion (Lee et al., 2016). The World Health Organization, 2018 (WHO) pointed out that if the goal of a 2 °C temperature rise under the Paris Agreement is achieved, more than one million premature deaths will be avoided every year in the world by 2050, and the health co-benefits will be twice the cost of emission reduction (World Bank, 2010). China's net income is projected to be US $290–2310 billion (Vandyck et al., 2018). Several empirical studies have also evaluated the effectiveness of environmental regulations from a cost−benefit perspective, such as clean heating (Feng et al., 2021a), straw recycling (He et al., 2020), and high-quality gasoline standards (Li et al., 2020). This evidence from cost−benefit analysis can provide policy-makers with more comprehensive evaluations of policy effectiveness. Hence, this study evaluates the costs, and health and economic co-benefits of production restrictions from the perspective of cost−benefit analysis.

The production restriction policy is a command-and-control environmental regulation adopted in China to curb the climate pollutant emissions of industrial enterprises on January 1st, 2015. According to the Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution, enterprises will be restricted from production under the following circumstances. First, the local government can start the emergency plan based on the early warning level of heavily polluted air quality, and can take compulsory emergency measures, including forcing polluting enterprises to stop production or restrict production, generally in autumn and winter (November to March of the following year). Second, in case of any unauthorized pollution discharge, excessive pollution discharge or pollution discharge evasion from supervision, the enterprise will be forced to restrict or stop production. Third, to ensure good air quality during major events, including APEC, Olympic Games, military parades, etc., enterprises will also be asked to restrict their production. Generally, the period for production restriction is at most three months. Enterprises are also allowed to refuse to implement production restrictions. Provinces and cities have made specific instructions on the production restriction and suspension of local industrial enterprises. Generally, the municipal governments issue production restrictions and suspension lists for industrial enterprises, mainly involving coal, steel, chemical, cement, building materials and other heavily polluting sectors.

Production restrictions directly reduce the production activities, energy consumption, and pollutant emissions of industrial enterprises. For example, to ensure good air quality during the military parade in 2015, 1927 industrial enterprises in Beijing implemented production restrictions, driving restrictions and other regulations. Under those series measures, the $PM_{2.5}$ concentration in Beijing was 19.5 $\mu g/m^3$, a record low (Xie, 2015).

However, the "one size fits all" production restriction policy has brought difficulties to the production and operation of industrial enterprises. Regardless of the size of the enterprises, production restrictions with the same intensity are adopted in the policy adoption process. It is easy to understand that due to production restrictions, the contribution of air pollution reduction for small enterprises may be lower than that for large enterprises, but the economic shock on small enterprises may be greater. When production is restricted or even stopped, it is more difficult for small enterprises to recover from economic losses. The technical level of small enterprises is also relatively backwards, which further makes it difficult to upgrade and improve technology quickly. Therefore, production restriction policies may lead to the closure or even bankruptcy of small enterprises.

In addition, the production restriction policy in some regions does not consider the specific characteristics of each industry and air pollutant type. For example, the cost of restarting after production restrictions for an enterprise in the steel industry is high. Frequent production restrictions will bring great economic losses to enterprises, which may hinder their sustainable development and transformation. Industrial enterprises are faced with the dilemma of environmental protection or economic development. On the one hand, according to the Porter hypothesis, production restrictions make enterprises take measures of technological improvement to reduce pollution (Porter and Linde, 1995). On the other hand, production restrictions will lead to economic and profits losses for enterprises (Lu et al., 2021), which in turn may affect investment in environmental protection.

Few studies examine the impacts of production restrictions. However, it is unclear how much the impacts of production restrictions on industrial enterprises' environmental and economic performance are. Furthermore, it is unknown how the decline in enterprises' economic benefits affects their environmental investment and green behaviour, thus affecting their environmental performance. In this regard, we investigate the effect and mechanism of production restriction to identify its regulatory effectiveness and provide enlightening suggestions for the coordinated development of the environment and economy.

Based on the panel data of industrial enterprises in China from 2016 to 2019, this paper examines the impacts of production restrictions on enterprises' environmental and economic performance. The impacts on environmental performance include the direct effects caused by the reduction of production activity and the indirect effects contributed by the loss of profits. The evaluations of economic performance include the income, expense, and profit of industrial enterprises with production restrictions. With regression models, we also explore whether the changes in economic benefits could affect the enterprises' environmental investment, thereby altering the environmental performance. Furthermore, a mediating effect model is used to assess the potential mechanisms by which production restrictions affect air pollution, including environmental protection investment, total factor production (TFP), and green patents. Three mediating variables are used to test the investment effect, technology effect, and Porter effect. In this paper, a series of robustness tests are conducted to check the reliability of the results, including alternative estimations with discontinuity design (RDD) and difference-in-differences (DID) models, to differentiate the intensity of policy, a falsification test, and potential influence bias. In addition, heterogeneity analysis and cost–benefit analysis of the health-economic benefits and economic losses contributed by production restriction are also discussed. Fig. 1 presents the research framework of this study.

This study contributes to the literature in the following three aspects. First, to the best of our knowledge, previous literature has yet to investigate the impacts of production restrictions on both enterprises' environmental and economic performance. Thus, our paper fills this gap. Second, this paper provides a theoretical explanation of the mechanisms regarding how enterprises' production restriction affects air pollution. That is, production restriction has a shock on the economic benefits, thus reducing the environmental protection investment and hindering the air pollution reduction of enterprises. Third, this study enriches the evaluation literature on command-control environmental regulations by exploring the effectiveness of production restrictions with cost–benefit analysis.

2. Theoretical hypothesis

Production restrictions have direct effects on the environmental and economic performance of industrial enterprises due to the decline in production. For the emission of air pollutants, restricted production will lead to a decline in the consumption of fossil energy in the production process, which will directly reduce the emissions of sulfur dioxide, nitrogen oxides, and other pollutants (Goforth and Nock, 2022; Qian et al., 2021). For the business performances of enterprises, the decline of production inevitably leads to the reduction of operating income, expenditures, and profit of enterprises. Moreover, the investment in environmental protection would also be cut due to the decline in profit. Hence, we propose the following Hypothesis *H1*.

H1. Production restrictions could mitigate air pollution and reduce the economic performance of enterprises.

Industrial enterprises may take the initiative to adopt several measures for pollution reduction, such as green technology or productivity improvement, to cope with production restrictions, which have mediating effects on environmental performance.

First, neoclassical economics argues that environmental policies increase private production costs and reduce the competitiveness of enterprises (Illge and Schwarze, 2009). The change in costs would offset the positive effects of environmental protection on society and produce negative effects on economic growth (Annicchiarico and Di Dio, 2015; Zhang et al., 2021b). However, Porter and Linde (1995) believed that environmental protection and economic development were not controversial. The Porter hypothesis states that reasonable environmental regulation could encourage enterprises to carry out more innovative activities, which turns out to offset the costs of environmental protection and improve the profitability of enterprises in the market (Porter, 1991; Porter and Linde, 1995). Based on Porter's hypothesis, production restrictions can encourage enterprises to adopt green technology innovations so that they reduce air pollutant emissions and no longer appear on the black list of production restrictions. Moreover, green innovation could bring the economic benefits of cost savings and product quality improvement, which can compensate for its cost input in the long run (Chen et al., 2022). Based on the above analysis, we propose the following Hypothesis *H2*.

H2. Production restrictions could mitigate air pollution through the mediating effect of green technology innovation.

Second, according to the "innovation offsets" theory, environmental regulations could improve environmental performance through total factor productivity (TFP) (Porter and Linde, 1995). Polluting enterprises are also motivated to indirectly reduce air pollution by improving production efficiency, so that they are not subject to the regulation of production restrictions. When faced with the increasing environmental compliance costs caused by production restrictions, enterprises seeking to maximize profits can flexibly choose to improve production efficiency to reduce production costs, and ultimately offset the cost pressure (Chen et al., 2021). Hence, we propose the following Hypothesis *H3*.

H3. Production restrictions could mitigate air pollution through the mediating effect of total factor productivity.

Third, polluting enterprises have the motivation to increase their investment in environmental protection under environmental regulations, because environmental investment can promote enterprises' efforts to mitigate pollution emissions and reduce the economic losses caused by the regulation (Guan et al., 2022; Zhang et al., 2021a). However, as we discussed in *H1*, production restrictions could significantly drop the income and profit of polluting enterprises, which may lead to the shrinkage of investment in environmental protection. The decline in environmental investment is likely to hinder air pollution reduction and violate the original intention of the production restriction policy. Thus, we point out the following Hypothesis *H4*.

H4. Production restrictions could reduce investment in environmental protection, which would hinder the environmental improvement of enterprises.

3. Research design

3.1. Research sample

This study uses daily data, with industrial enterprises in China as the research sample, to identify the impacts of production restrictions on their economic performance and air pollution control. According to the enterprises' list provided by the Institute of Public and Environmental

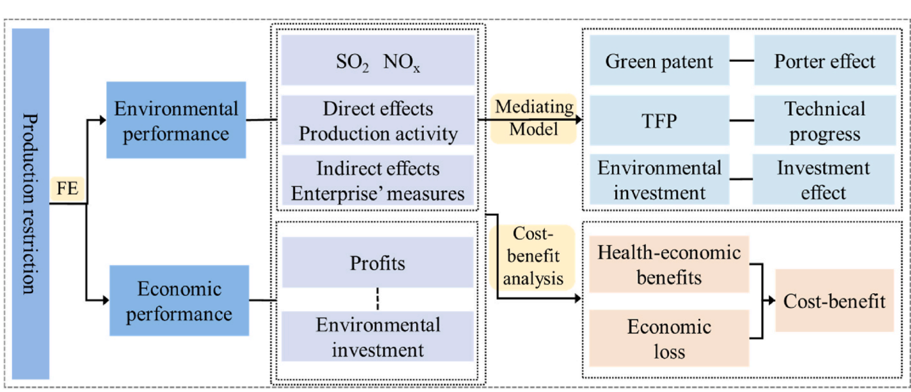

Fig. 1. Research framework.

Affairs (IPE), 98 industrial enterprises have been restricted in production for a specific period of time since October 2017. Among them, sulfur dioxide (SO_2), nitrogen oxide (NO_x) and soot are the main pollutants, especially for 52 enterprises. To obtain the data on air pollutant concentrations emitted by industrial enterprises, we match the 98 production restriction enterprises with the list of industrial enterprises under emission supervision collected from the IPE database. As a result, our analytical sample for this analysis contains 31 industrial enterprises, located in 9 Chinese provinces and municipalities, including Hebei, Shaanxi, Hubei, Anhui Shandong, Henan, Jiangsu, Ningxia and Beijing. These enterprises involve seven industries, including the power and heat production and supply industry, nonmetallic mineral products industry, chemical materials and chemical products manufacturing industry, engineering construction industry, fuel processing industries, metal products industry, ferrous metal smelting and rolling processing industries. All seven industries are high-pollution and energy-consuming sectors. Detailed information on 31 industrial enterprises, such as business name and duration of production restriction, is shown in Table S1.

3.2. Research approach

Here, we apply the fixed effects model to examine the impacts of production restrictions on enterprises' air pollution and economic performance. In addition, a mediating effect model is used to identify how production restrictions affect air pollution and whether the Porter hypothesis exists.

3.2.1. Fixed effects model

We examine the impacts of production restrictions on enterprises' air pollution and economic performance with the following two-way fixed effects model:

$$y_{it} = \beta_0 + \beta_1 restriction_{it} + \sum \beta_j X_{it} + \gamma_t + \delta_i + \varepsilon_{it} \tag{1}$$

where the dependent variable y_{it} includes the daily average concentrations of SO_2 and NO_x to reflect the influence on air pollution control, and the net profit, the logarithm of total operating revenue and the financial expenses to reflect the influence on economic performance, denoted *SO_2, NO_x, profit, lnREV,* and *expense*, respectively; where *i* and *t* present the enterprise and the date, respectively. The independent variable $restriction_{it}$ in Eq. (1) is a dummy variable; if enterprise *i* has a production restriction on date t, the value is one, and the others are zero. X_{it} is the control variable, which includes the number of patents, net profit, fixed asset net volume, total operating revenue, management cost, financial expenses, number of employees, total factors of productivity and investment in environmental protection. γ_t and δ_i represent the enterprise fixed effect and the time fixed effect, respectively. ε_{it} is the error term.

3.2.2. Mediating effect model

To identify how production restrictions affect air pollution, we examine whether investment in environmental protection, green technology innovation and total factor productivity have mediating effects. The mediating effect models are as follows:

$$m_{it} = \theta_0 + \theta_1 restriction_{it} + \sum \theta_j X_{it} + \gamma_t + \delta_i + \varepsilon_{it} \tag{2}$$

$$y_{it} = \alpha_0 + \alpha_1 restriction_{it} + \alpha_2 m_{it} + \sum \alpha_j X_{it} + \gamma_t + \delta_i + \varepsilon_{it} \tag{3}$$

where m_{it} represents the mediating variables, including the investment in environmental protection ($ln\ INV_{it}$), the number of green patent applications ($patent_{it}$), and total factor productivity (TFP_{it}). In the first step, we apply Eq. (1) to examine whether production restrictions have significant impacts on reducing the air pollution concentrations of enterprises. If β_1 is significant, then go to the second step to test whether θ_1 in Eq. (2) and α_2 in Eq. (3) are significant. Therefore, θ_1 reflects the impacts of production restriction on the mediating variable, while α_2 reflects the impacts of the mediating variable on enterprises' pollution concentrations. Thus, either $\alpha_1 < \beta_1$ or the changed significance of β_1 indicates that the mediating effects are exerted.

3.3. Data source

We merged multiple datasets at the enterprise-level from different databases to conduct this analysis. The study period was from January 1st, 2016, to December 31st, 2019. The daily air pollutant concentration (including NO_x and SO_2) data of each enterprise with production restrictions come from the IPE database (http://www.ipe.org.cn/IndustryRecord/Regulatory.html). The number of green patents applied by each enterprise comes from the National Intellectual Property Patent database. Net income comes from Market Data of Listed Companies of NetEase Finance. Data on net fixed assets, total operating revenue, management cost, financial expenses, and number of employees are obtained from the CMSAR Database (China Stock Market & Accounting Research). Total factor productivity is calculated according to the LP method (Levinsohn and Petrin, 2003). Environmental protection investment is compiled from the disclosure report of listed companies. Table S2 presents the summary statistics of key variables.

4. Empirical results and discussion

4.1. Impacts of production restrictions on air pollution

We estimate the effects of production restrictions on enterprises' air pollution. The results of the estimations on NO_x and SO_2 are shown in Table 1. Control variables are included, and enterprise-level fixed effects and daily fixed effects are controlled in all results. In Columns (1) and (2) of Table 1, the coefficients of *Restriction* are significantly negative with FE model estimations, which indicates that production restriction dropped NO_x emitted from polluting enterprises significantly by 75.173 μg/m^3 (25.6%). In Columns (3) and (4), the coefficients of *Restriction* are significantly negative, which indicates that production restriction dropped SO_2 emitted from polluting enterprises significantly by 10.107 μg/m^3(32.3%).

Production restriction policies can both directly and indirectly impact the reduction of air pollution. On the one hand, the restriction of production would directly mitigate production activity and reduce air pollution. On the other hand, production restriction is an environmental regulation for polluting enterprises. If the air pollutants of these enterprises can be reduced or reach the standard, they will not be faced with stringent regulation, and their production activity and income will not be affected. Hence, polluting enterprises are motivated to indirectly reduce air pollution by improving production efficiency or upgrading technology, so that they are not subject to the regulation of production restrictions.

Table 1
Effects of production restrictions on enterprises' air pollution.

	NO_x	ln (NO_x)	SO_2	ln (SO_2)
	(1)	(2)	(3)	(4)
Restriction	−75.173***	−0.256***	−10.107***	−0.323***
	(5.836)	(0.251)	(3.010)	(0.269)
Control Variable	Yes	Yes	Yes	Yes
Enterprise FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	45,291	45,291	45,291	45,291
R^2	0.711	0.713	0.415	0.422

Notes: Standard errors are in the parentheses and are clustered at enterprise and daily level. ***p < 0.01; **p < 0.05; *p < 0.1.

4.2. Impacts of production restriction on enterprises' economic performance

Production restriction or shutdown will inevitably affect the trade and economic income of enterprises. Moreover, the decline in income may also affect profits, investments, expenditures, etc. It is also possible that enterprises make efforts to reduce air pollution through technological progress, so that they will no longer be on the list of highly polluting enterprises with production restrictions, and production and trade will not be affected.

This paper examines the impact of production restrictions on enterprises' economic performance, including operating income (*income*), financial expenses (*expense*), net profit (*profit*), investment in environmental protection (*envir_invest*), and the number of green patent applications (*patent*). The results are shown in Table 2. The coefficients of restriction are significant and statistically significant at the 1% confidence level across all columns. In Column (1), we find that the production restriction reduced the annual income of each enterprise by 702.6 million CNY on average. The decline in output would inevitably lead to a decline in trade volume and operating income. The results in Column (2) show that the financial expenses of polluting enterprises decreased significantly by 104.1 million CNY caused by production restrictions, which is mainly due to the reduction in production factor expenditures, such as raw materials, electricity consumption, labour cost. Although both expense and income decreased, the net profit of polluting enterprise was significantly negatively dropped by 169.1 million CNY per year due to production restrictions, as shown in Column (3). The decrease in profit and income may cause enterprises to tighten their expenditures, including expenditures for environmental protection investment. Although according to Porter's hypothesis, enterprises are motivated to achieve green development through technological progress when faced with stricter environmental regulations, the direct impact of reducing income will still cut enterprises' investment in environmental protection. In Column (4), the coefficient of *Restriction* is significantly negative, which indicates that investments in environmental protection are also decreased by 29.5 million CNY. To get out of the blacklist of production restrictions, polluting enterprises are trying to be clean through technological improvements and innovations.

Production restrictions lead to direct economic losses, such as a reduction in income, but also they also cut investment in environmental protection. Enterprises are faced with the dilemma of economic development and environmental protection. Because of the reduction in direct income, they cannot reduce air pollution through environmental protection investment, but they still have the motivation to reduce pollution. If enterprises are not restricted in production, they will have more funds to invest in environmental protection, but perhaps their motivation to reduce air pollution is less urgent.

4.3. Mechanism analysis

According to the above analysis, production restriction contributes to the decline in air pollution. However, it remains unknown how this regulation affects the air pollutants emitted by polluting enterprises. On the one hand, the restriction of production would directly reduce air pollutants. Polluting enterprises are also motivated to indirectly reduce air pollution by improving production efficiency or upgrading technology so that they are not subject to the regulation of production restrictions. On the other hand, the restriction of production leads to a drop in the profit of polluting enterprises and a shortage of investment in environmental protection, which may have a negative effect on air pollution reduction. Hence, to verify whether technology innovation, environmental investment, and total factor productivity are transmission channels for the impacts of production restriction on the environmental performance of enterprises, this study further identifies the mediating effect. Table 3 presents the results of mediating effects estimated by Eqs. (2) and (3).

First, we test the mediating effect of green patents. As shown in Column (1), production restrictions have significantly improved green patent applications by 0.26 units, which proves that polluting enterprises are motivated to improve their environmental performance by developing green technologies. In Columns (2) and (3), the policy variable (*Restriction*) and mediating variable (*Patent*) are incorporated, where the coefficients of the policy variable are still significant. The absolute values of the coefficients of production restriction shown in Columns (2) and (3) are smaller than those in Column (2) (0.256***) and Column (4) (0.323***) of Table 1. Moreover, the influences of patents in Columns (2) and (3) on enterprises' air pollution are significantly negative, which indicates there is a direct effect. The signs of the coefficients of $\theta_1 * \alpha_2$ are the same as those of α_1, suggesting that production restrictions can mitigate the air pollution of enterprises through green patents.

Second, the mediating effects of investment in environmental protection are tested. The results shown in Table 3 have proven that production restrictions significantly decreased the investments in the environmental protection of polluting enterprises due to the shortage of economic profit (Column (4)). As shown in Columns (4) and (5), the coefficients of the policy variable (*Restriction*) are still statistically significant, but their absolute values are higher than those in Column (5) of Table 1. The coefficients of the mediating variable (investment in environmental protection) are significantly negative. The signs of the coefficients of θ_1 (Column (4) of Table 3)* α_2 (Columns (4) and (5) of Table 3) are different from those of α_1 (Columns (4) and (5) of Table 3), suggesting that there is a masking effect. This indicates that the reduction in environmental protection investment hinders the enterprise's efforts to control air pollution.

Third, we evaluate the mediating effects of total factor productivity on pollutant concentrations. In Column (6) of Table 3, the coefficient of the policy variable (*Restriction*) is significantly positive, which indicates that TFP is increased by production restriction. Production restrictions drop the income and profit of polluting enterprises, and they cannot achieve economic growth by increasing labour and capital inputs. Therefore, enterprises improve total factor production efficiency through mechanism reform or technology upgrading. In Columns (7) and (8), the policy variable (*Restriction*) and mediating variable (*TFP*) are incorporated, where the coefficients of the policy variable are still significant. The absolute values of the coefficients of production restriction shown in Columns (7) and (8) are smaller than those in Column (2) (0.256***) and Column (4) (0.323***) of Table 1. Moreover, the influences of TFP in Columns (7) and (8) on enterprises' air pollutant concentrations are significantly negative, which indicates that there is a direct effect. The signs of the coefficients of $\theta_1 * \alpha_2$ are the same as those of α_1, suggesting that TFP plays a mediating role in the impact of production restrictions on enterprises' air pollutant concentrations. Thus, the mediating effects of patents and TFP verify the existence of the Porter hypothesis.

Table 2
Effects of production restrictions on enterprises' economic performance.

	income	expense	profit	envir_invest
	(1)	(2)	(3)	(4)
Restriction	−7.026***	−1.041***	−1.691***	−0.295***
	(1.817)	(0.063)	(0.074)	(0.040)
Control variable	Yes	Yes	Yes	Yes
Enterprise FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	45,291	45,291	45,291	45,291
R^2	0.864	0.622	0.358	0.559

Notes: Standard errors are in the parentheses and are clustered at enterprise and daily level. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 3
The mediating effects of production restrictions on air pollutants.

	Patent	ln (NO_x)	ln (SO_2)	ln (NO_x)	ln (SO_2)	TFP	ln (NO_x)	ln (SO_2)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Restriction	0.026***	−0.213***	−0.262***	−0.271***	−0.339***	0.002***	−0.226***	−0.278***
	(0.007)	(0.214)	(0.271)	(0.278)	(0.311)	(0.000)	(0.221)	(0.292)
Patent		−1.343***	−2.178***					
		(0.385)	(0.416)					
Invest_envir				−0.052***	−0.054***			
				(0.325)	(0.367)			
TFP							−16.701***	−21.506***
							(0.911)	(0.875)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	45,291	45,291	45,291	45,291	45,291	45,291	45,291	45,291
R^2	0.367	0.707	0.405	0.703	0.422	0.589	0.710	0.451

Notes: Standard errors are in the parentheses and are clustered at enterprise and daily level. ***p < 0.01; **p < 0.05; *p < 0.1.

4.4. Robustness tests

We set a series of robustness tests to check the reliability of the results.

First, to verify the robustness of the model, we employ the regression discontinuity design (RDD) and difference-in-differences (DID) model to estimate the impacts on environmental performance. RDD can show whether there is a "jump" in air pollution concentrations during and after the adoption of production restrictions (Li, 2017; Viard and Fu, 2015). We add local linear term $f(t)$ to reflect the small window. Several studies used RDD with global high-order polynomial regressions (Bento et al., 2014). RDD estimations are sensitive to high-order polynomials (Gelman and Imbens, 2014; Gelman and Zelizer, 2015). Hence, this paper uses local linear and quadratic regressions of RDD estimations. Table S3 reports the results. The NO_x and SO_2 concentrations significantly dropped by 72–79 μg/m^3 and 14–20 μg/m^3, respectively. The results of RDD estimations are consistent with those presented in Table 1.

We also employ the DID model to estimate the impacts on air pollutants. The DID model setting is presented in the supplementary materials. The estimation results of the DID model are shown in Panel 1 of Table 4. The coefficients of the interaction terms *Trt*Post* are stable and statistically significant at the 1% level. When the enterprises were restricted for production, the concentrations of NO_x and SO_2 decreased by 76.071 μg/m^3 (26.1%), and 8.626 μg/m^3 (32.9%), respectively, and the business performance of enterprises also declined.

Second, four enterprises have implemented different intensities of production restriction, ranging from 2% to 72% in different months. To identify the impacts of different intensities of production restriction, we replace *restriction* with $restriction\_intensity_{it}$ as the independent variable. $restriction\_intensity_{it}$ is a discrete variable, and its value ranges from zero to 1. The results are shown in Panel 2 in Table 4, which shows that the impacts of partial production restrictions on air pollutants are slightly lower than those of overall production restrictions.

Third, to exclude the possible impact of other random factors on the environmental and economic performance of polluting enterprises, this paper randomly sets the start time of the production restriction policy and conducts a time placebo test (Chetty et al., 2009; La Ferrara et al., 2012). Using the Monte Carlo simulations, we randomly selected the start time of the policy, repeated this process 500 times and obtained 500 coefficients $\widehat{\beta}^{random}$. Fig. 2 shows the distribution of 500 random estimated coefficients. It can be seen that all coefficients $\widehat{\beta}^{random}$ are concentrations near zero and present a normal distribution. The results of the time-placebo test prove that the above estimation results are not biased by other factors and that the placebo effect does not exist.

Fourth, the air pollutant concentrations of enterprises are inevitably affected by other environmental policies, which may lead to the deviation of our results. To test the robustness of our results, we select a low-carbon pilot city (LCPC) and emission trading scheme (ETS) and add

Table 4
Robustness checks.

	NO_x	SO_2	income	expense	profit	envir_invest
	(1)	(2)	(3)	(4)	(5)	(6)
***Panel 1**: DID estimation*						
Trt**Post*	−76.071***	−8.626***	−6.931***	−1.123***	−1.571***	−0.291***
	(4.025)	(1.775)	(1.721)	(0.055)	(0.051)	(0.030)
Observations	45,291	45,291	45,291	45,291	45,291	45,291
R^2	0.702	0.415	0.873	0.615	0.361	0.548
***Panel 2**: independent variable: the intensity of production restriction*						
Restriction_intensity	−75.142***	−10.102***	−7.124***	−1.245***	−1.716***	−0.293***
	(5.836)	(3.010)	(1.459)	(0.044)	(0.037)	(0.028)
Observations	45,291	45,291	45,291	45,291	45,291	45,291
R^2	0.722	0.418	0.851	0.615	0.384	0.589
***Panel 3**: excluding the impacts of LCPC and ETS*						
Restriction	−74.168***	−9.841***	−7.008***	−1.022***	−1.648***	−0.288***
	(5.812)	(2.942)	(1.741)	(0.061)	(0.070)	(0.036)
LCPC	−1.251*	−0.412*	−0.012	−0.004	−0.002	0.015
	(0.551)	(0.124)	(0.044)	(0.001)	(0.001)	(0.007)
ETS	−0.142	−0.101	−0.005	−0.004	−0.002	0.032
	(0.056)	(0.015)	(0.002)	(0.002)	(0.001)	(0.007)
Observations	45,291	45,291	45,291	45,291	45,291	45,291
R^2	0.715	0.482	0.877	0.634	0.367	0.563

Notes: Standard errors are in the parentheses. All models add control variables, enterprise fixed effects, time fixed effects***p < 0.01; **p < 0.05; *p < 0.1.

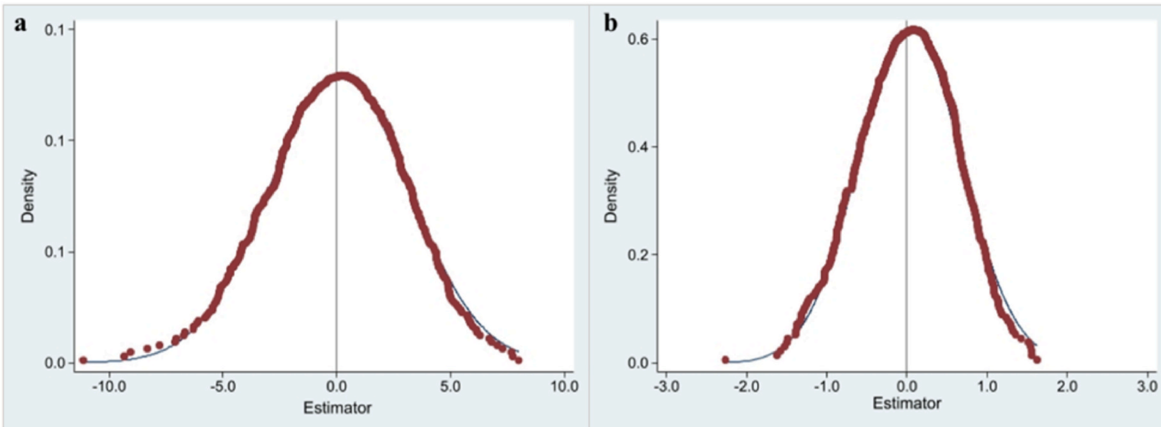

Fig. 2. Placebo test of adoption time. (a) NO_x concentrations. (b) SO_2 concentrations.

them as the dummy variable of environmental policies in the basic model. LCPC has been implemented in Chinese cities since 2010 and has affected the carbon intensity, carbon emissions, and air pollution of Chinese cities (Chen et al., 2023; Feng et al., 2021b; Pan et al., 2022). Thirteen enterprises in our sample are located in the pilot cities or provinces of the LCPC programme, which may bias the estimation results of this paper. Hence, we add the dummy variable LCPC in basic models. The values of the variable *LCPC* of these enterprises are defined as one. ETS is an effective regulation for the reduction of carbon emissions and air pollution (Li et al., 2018; Liu et al., 2021a; Liu et al., 2021b; Zhang et al., 2021a). There are five enterprises in our sample located in the pilot provinces of the ETS. To avoid biased estimation, we add the dummy variable of ETS in basic models. As shown in Panel 3 of Table 4, the LCPC programme decreases the concentrations of NO_x and SO_2 at the 10% significance level, and the LCPC programme and ETS do not affect the economic performance of polluting enterprises. The coefficients of *Restriction* are still significant and are consistent with those in Table 1.

4.5. Heterogeneity analysis

The above estimation results show that production restrictions drop air pollutant concentrations and mitigate the economic benefits of industrial enterprises. It is unknown whether there are heterogeneity effects among different enterprises. Based on the employees, operating income and other indicators, small and medium-sized industrial enterprises can be divided into medium-sized, small-sized and microsized enterprises. Fifteen enterprises are small-sized enterprises (more than 20 employees or more than 3 million yuan and less than 20 million yuan of operating income), and the other sixteen enterprises are microsized enterprises (fewer than 20 employees, less than 3 million yuan of operating income). We examine the impacts of production restrictions on environmental and economic performance using samples of small enterprises and microenterprises, respectively. For the comparability of the estimated coefficients between the subsample groups of small enterprises and microenterprises, we used the logarithm of the explained variable for heterogeneity analysis. The results of heterogeneity effects are shown in Fig. 3. For the impacts on environmental performance, production restriction decreases the concentrations of NO_x and SO_2 of small enterprises by 28.3% and 37.1%, respectively. The values of the microenterprises are 21.4% and 24.2%. For the impacts on economic benefit, the operating income, expense, profit, and environmental protection investment of both small enterprises and microenterprises drop significantly. The decline in the former group is less than 0.5%, and that in the latter group is more than 1%, which indicates that the economic shock caused by production restrictions on microenterprises is larger. In general, the economic strength of microenterprises is poor, and it is difficult to invest more capital in environmental protection and upgrade

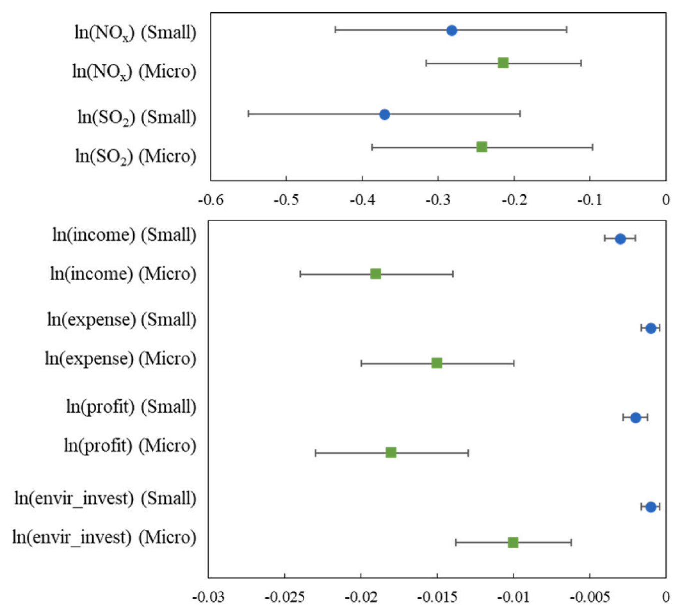

Fig. 3. Heterogeneity analysis between small enterprises and microenterprises. Notes: The blue circles represent the coefficients of Restriction with samples of small enterprises; the green squares represent the coefficients of *Restriction* with samples of microenterprises. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

technology when economic income drops, and even this economic loss may cause them to close down. Implementing production restrictions for microenterprises may be a way to eliminate their backwards production capacity.

4.6. Cost–benefit analysis

Production restriction is an environmental regulation to address air pollution in autumn and winter in Chinese cities. In general, cost–benefit analysis can provide evidence for examining the effectiveness of policy from the perspective of the environmental economy (Feng et al., 2021a; Li et al., 2020). In this section, this paper evaluates the impact of production restrictions on urban air pollution and analyses the cost–benefit of this policy.

Benefits. Table S4 presents the estimation results of the impacts on air pollution at the city level. In Columns (1)–(4), the concentrations of $PM_{2.5}$, PM_{10}, SO_2, and NO_x decreased significantly by 1.172 $\mu g/m^3$, 1.321 $\mu g/m^3$, 0.176 $\mu g/m^3$, and 0.793 $\mu g/m^3$, respectively, which indicates that production restriction is an effective regulation for urban air pollution control. $PM_{2.5}$ and PM_{10} are the main pollutants of air pollution, and are harmful to human health (Gehrsitz; Han et al., 2020; Xie et al., 2016). Several studies have examined the health co-benefits related to PM reduction in China. Ebenstein et al. (2017) evaluated the impacts of central heating on PM_{10} and found that a 10 $\mu g/m^3$ growth in PM_{10} decreases life expectancy by 0.64 years. When combined with the value of a statistical life (VSL) given by World Bank (2010), the monetized mortality cost for each 10 $\mu g/m^3$ growth in PM_{10} in China is US$ 13.4 billion. Barwick et al. (2018) proved that a 10 $\mu g/m^3$ decline in $PM_{2.5}$ in China is related to a US$ 9.2 billion savings in health expenditure. Applying the coefficients of $PM_{2.5}$ and PM_{10} shown in Table 8S4, production restriction implies US$1.77 billion savings from avoided mortality and US$1.08 billion savings from avoided morbidity. In total, the health-economic benefit from production restriction was up to US $2.85 billion.

Costs. Economic loss caused by the reduction in production activity is the main cost of production restriction. The accumulated net profit loss of polluting enterprises with production restrictions in three years reached US$0.71 billion (169.1 million CNY per year, see Table 3). The cost of policy implementation and management, as well as the potential losses of the enterprises, such as customer loss and liquidated damages, are not calculated in the cost. Although the health-economic benefits of the policy are greater than the economic loss of polluting enterprises, it is still necessary to note that this is at the expense of the economic benefits of the enterprise, not the coordinated development of the environment and economy.

5. Conclusion and policy implications

Using panel data on industrial enterprises in China from 2016 to 2019, this paper evaluates the impact of production restrictions on both enterprises' environmental and economic performance with regression models. In this paper, we also explore whether changes in economic benefits could affect enterprises' environmental investment, thereby altering their environmental performance. Furthermore, to assess the potential mechanisms by which production restrictions affect air pollutants, we use a mediating effect model to test the investment effect, technology effect, and Porter effect. In addition, heterogeneity analysis of enterprises' scales as well as cost–benefit analysis of the health-economic benefits and economic losses contributed by production restriction are also discussed.

Several major findings follow. First, we find that production restrictions significantly drop the concentrations of SO_2 and NO_x emitted from polluting enterprises. Economic income, expense, profit, and environmental protection investment are also significantly decreased because of production restrictions. Those are confirmed by the robustness checks. Second, the mechanism analysis reveals that production restrictions mitigate air pollutant concentrations by increasing the number of green patents and improving total factor productivity (TFP). Those results also verify the Porter hypothesis, i.e., Reasonable environmental policies can achieve a win–win situation for both economic development and environmental protection. However, there is a masking mediating effect of environmental investment. This indicates that the reduction in environmental investment hinders the enterprise's efforts to control air pollution. Third, the heterogeneous analysis shows that the economic shock of the production restriction on the micro enterprises is larger than that on the small enterprises. Thus, implemening production restrictions for microenterprises may be a way to eliminate their backwards production capacity. Fourth, based on the cost–benefit analysis, we find that for polluting industrial enterprises, the health-economic benefits of production restrictions are greater than their economic losses. However, the larger economic losses of enterprises caused by production restriction policies should be taken seriously since these policies cannot reconcile economic development and environmental protection goals.

Given the above findings, we propose three policy implications that could help to promote a win–win situation for both economic development and air pollution reduction. First, the "one size fits all" production restriction policy applies to all heavy polluters, regardless of their enterprise sizes and total emissions of different pollutants. On the one hand, production restriction affects the enthusiasm of enterprises to reduce emissions. No matter how much air pollution they reduce, as long as they are still on the production restriction list, they must be shut down. On the other hand, production restriction reduces the profits and investment in the environmental protection of enterprises, which is not conducive for enterprises to control air pollution in the long run. Therefore, dynamically adjusting the enterprises list of production restrictions based on enterprises' emission reduction is a recommended way to improve their enthusiasm for emission reduction. Second, regardless of country or enterprises, controlling air pollution at the expense of enterprise development is not a sustainable solution. To stimulate green transformation for each enterprise, environmental taxes, carbon trading and other marketing economic incentive measures could be a better alternative for production restriction. On the one hand, in order to seek economic benefits, enterprises will take the initiative to take emission reduction measures, improve green production, and achieve pollution control. On the other hand, the reduction of pollution emissions can make enterprises obtain more rent-seeking opportunities for emissions trading, and may also reduce the pollution costs of enterprises, thus improving the economic benefits. Third, our study finds that the "one size fits all" production restriction policy makes it difficult for the microenterprises to recover from the shutdown and to improve their green efficiency. It is well known that small and microenterprises are important components of the national economy. Hence, a "one enterprise, one policy" production restriction plan is more recommended than the "one size fits all" policy. The government may customize the production restriction plan for each enterprise by its specific characteristics, such as scale, industry, and region.

This study should be considered a first step towards understanding the impact of environmental regulation on an enterprise's economic and environmental performance. However, there are also some limitations of this study. First, only 31 enterprises remain after matching the dataset of production restriction enterprises with the emission dataset. Thus, our sample size is too small to analyse the industry heterogeneity. Second, due to data limitations, we only considered the mediating effects of three variables (technology innovation, environmental investment and total factor productivity) and did not analyse other possible potential effects, such as green total factor productivity, which will be discussed in future studies. Third, it is worth noting that enterprises will be forced to restrict or stop production under production restriction policies. However, in this paper, we only focused on the overall effect of the production restriction policy on industrial enterprises' economic and environmental performance and did not separate the effect of stopping production or restricting production, which will be estimated if data are available.

Credit author statement

Tong Feng: Methodology, Resources, Writing - original draft, Writing – review &editing. Xinyu Chen: Resources, Writing – original draft. Jie Ma: Writing – editing. Yuechi Sun: Writing – editing. Huibin Du: Supervision. Ye Yao: Writing – review & editing. Zhenni Chen: Resources. Shidong Wang: Supervision. Zhifu Mi: Supervision.

Declaration of competing interest

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Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.117611.

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