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RESEARCH ARTICLE

Effect of foreign direct investment on firms' pollution intensity: evidence from a natural experiment in China

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Abstract
This paper examines a causal relationship between foreign direct investment (FDI) and firms' pollution intensity by exploiting the policy of China's FDI access relaxation in 2002. The result shows that FDI leads to a significant reduction in firms' pollution intensity. The mechanism tests find that FDI reduces pollution intensity by increasing firms' productivity, pollution management abilities, and the output of lightly polluting firms. The effect primarily acts on firms in lightly polluting industries and firms in the eastern region. The findings support the pollution halo hypothesis and provide implications for developing countries like China by evaluating the effectiveness of policies to attract FDI.

Keywords: FDI access relaxation; FDI; firm level; pollution intensity

JEL classification: Q56; F21

1. Introduction

While foreign direct investment (FDI) brings development opportunities to emerging economies, it also raises concerns about the potential for serious environmental issues in the host countries. Taking China, a typical representative of developing economies utilizing FDI, as an example, this study investigates the impact of FDI on firms' pollution intensity, aiming to contribute to both the literature and policymaking.

There is an ongoing debate[1] regarding the impact of FDI on pollution emissions in host countries. Some argue that developed countries may transfer pollution-intensive industries to developing nations through multinational investments (Copeland and Taylor, 1994; Sarkodie and Strezov, 2019; Cheng *et al.*, 2020). However, others contend that

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[1] Many studies have been conducted to explore the effect of FDI on the environmental performance of Chinese firms, but their conclusions are not consistent. We summarize and list the method, data, and main findings of the related empirical literature in online appendix B.

the knowledge and technology spillovers from multinational corporations can promote the development and green technology upgrading of host countries (Jiang *et al.*, 2018; Hille *et al.*, 2019; Kong *et al.*, 2020).

Given the opposing theoretical predictions on the effect of FDI on pollution, this issue is ultimately an empirical one. Identifying the causal impact of FDI on pollution is a challenge because FDI is an ongoing phenomenon endogenously determined by the economic growth of the host country. The association between FDI and pollution may reflect unobserved variations in growth. Therefore, we need an identification method to isolate other macroeconomic factors.

To establish causality, this paper introduces the policy of China's FDI access relaxation in 2002 as an exogenous shock. This policy was based on China's commitments during its negotiations to join the WTO, a process that took about 15 years, making this policy change largely unpredictable for domestic firms (Kong *et al.*, 2022*a*). Moreover, the policy led to a significant inflow of FDI (Lu *et al.*, 2017), indicating its substantial economic significance. The plausibly exogenous changes in FDI regulation policy provide a good opportunity to address the endogeneity issue.

We conducted a difference-in-differences (DID) estimation based on the FDI access relaxation policy. We treated firms within industries affected by FDI relaxation as the treatment group and firms within industries that did not experience policy changes as the control group. The baseline analysis shows that FDI significantly reduces firms' pollution intensity. However, China began to pay attention to environmental protection during this period and introduced several environmental regulation policies, which may bias our results. Therefore, we conducted a series of robustness checks to filter out the impacts of several important environmental regulations, including the Eleventh Five-Year Plan (11FYP) and other regional or industrial environmental regulations, as well as other economic reforms. All the findings support the main results.

The mechanism tests find that FDI reduces the pollution intensity of firms by increasing productivity, pollution management abilities, and the output of lightly polluting industries. The heterogeneity analysis shows that the pollution intensity reduction effect of FDI primarily acts on firms in lightly polluting industries and firms in the eastern region.

This study contributes to the literature in three aspects. First, it adds to the broad literature on the environmental effect of FDI on manufacturing firms. The studies of Bu *et al.* (2019), Huang and Chang (2019), and Jiang *et al.* (2014) focus on the positive correlation between foreign ownership and environmental performance. The environmental effects of FDI that are concluded based on correlation may be biased. Another strand of literature examines the impact of environmental regulation on firms' pollution transfer behaviors (Bu and Wagner, 2016; Wu *et al.*, 2017; Zhang *et al.*, 2020; Xu *et al.*, 2021). However, conclusions within this literature are not unanimous regarding the existence of pollution transfer. Even the studies that support the idea that environmental regulations may lead to pollution transfer indicate that this phenomenon occurs in both domestic and foreign firms, which fails to suggest that the environmental impact of FDI differs from that of domestic firms.

Our study differs from these studies in that we focus on the causal effect of FDI on manufacturing firms' pollution intensity, and we establish an identification framework to mitigate the endogeneity problem in existing studies. Our study complements existing studies by offering a new research perspective, along with robust causal and direct evidence.

Second, this study adds to the literature that analyzes the pollution behavior of manufacturing firms in China from a micro perspective. Due to data limitations, previous studies mainly use indirect indicators as proxies for firms' environmental behavior. For instance, Bu *et al.* (2019) investigated the energy intensity of firms in Jiangsu province, while Kong *et al.* (2020) delved into the innovation behaviors of energy firms. In a similar vein, Huang and Chang (2019) employed sewage charges as a proxy for pollution costs. Jiang *et al.* (2014) provide a detailed statistical and fundamental analysis of the pollution intensity of firms with different ownerships, which is an important inspiration for our study. However, their conclusions are still confounded by data limitations and endogeneity issues. They only include pollution emission data for heavily polluting firms in 2006 and 2007.

Our study differs from these research studies in that we directly examine the effect of FDI on pollution intensity using a unique and comprehensive firm-level database specifically from China. Moreover, we use different types of emission indicators to enhance the credibility of the data. Our findings provide a direct reflection of the overall impact of FDI on pollution intensity of manufacturing firms, thus representing an important addition to existing research.

Third, our study provides new influencing channels for the pollution halo hypothesis. The existing studies supporting the pollution halo hypothesis are mainly based on the evidence of spillover effects from foreign firms on domestic firms. Our study differs from theirs in that we focus on the channels of FDI influencing firms' emissions and the different responses of firms in lightly and heavily polluting industries.

The discovery of this channel helps to resolve the debate between traditional viewpoints. The pollution haven hypothesis argues that FDI is attracted to heavily polluting industries in developing countries because of their lax environmental regulations. However, the factor endowment theory suggests that FDI is more likely to invest in lightly polluting industries, which are usually labor-intensive, following the comparative advantage with abundant labor (Cole and Elliott, 2005). Both our descriptive analysis and empirical results support the role of FDI in lightly polluting industries. These findings hold significant implications for developing countries seeking green development.

The remainder of this paper is organized as follows. Section 2 provides the conceptual framework. Section 3 describes the empirical framework. Section 4 presents the empirical results, and section 5 summarizes the conclusions.

2. Conceptual framework

We decompose the effect of FDI into the productivity, pollution management, and industry structure effects following equation (1), by extending the framework proposed by Copeland and Taylor (2004), as shown in online appendix A:

$$\ln E = -\ln\alpha - \ln\beta + \ln C, \tag{1}$$

where E is firms' pollution intensity, α is firms' productivity, β is firms' pollution management ability, and C is the industry structure effect. We further explain the three mechanisms below.

Productivity effect ($\ln\alpha$). Firms with higher productivity produce fewer pollutants with the same output (Wang and Zhu, 2021). In developing countries, FDI plays a vital role in technological progress through technology introduction and spillovers, which improve firms' productivity in host countries (Javorcik, 2004; Hille *et al.*, 2019).

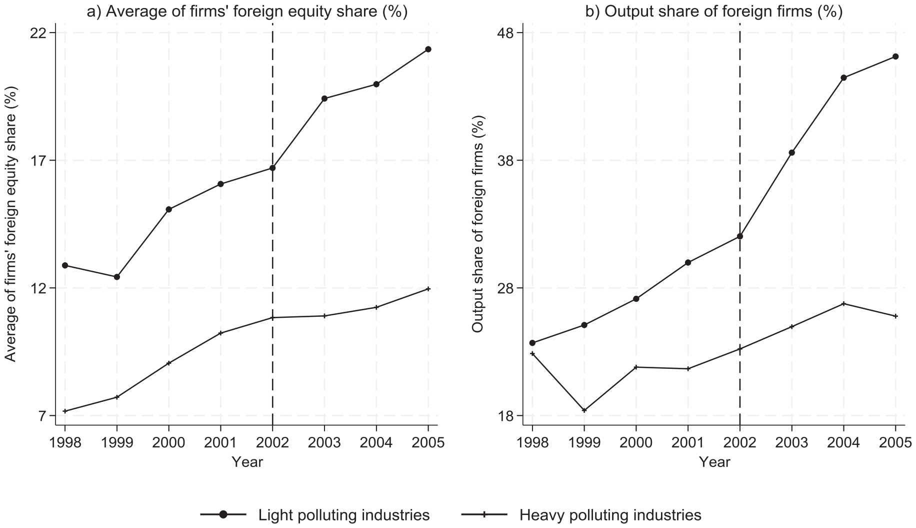

Figure 1. Trends of FDI and foreign firms' output share in heavily and lightly polluting industries.

Therefore, we assume that FDI inflows reduce pollution intensity by increasing firms' productivity.

Pollution management effect ($\ln\beta$). Firms' pollution management effects have two channels. The first channel is to change the energy structure. Firms use coal as an essential fuel in China. However, coal produces more pollution emissions than oil and natural gas. If firms reduce coal as fuel, they will produce fewer emissions for the same output. The second channel is to install waste management equipment to increase firms' endpoint pollutant management. We will use firms' SO_2 reduction rate to measure the endpoint pollutant management capacity. FDI may enable firms to invest in pollution management, so we assume that FDI reduces pollution intensity through the pollution management effect.

Industry structure effect ($\ln C$). The industry structure effect assesses the variation in pollution intensity caused by changing the share of heavily polluting products. Copeland and Taylor (2004) suggest that as heavily polluting products are capital-intensive, FDI inflows will increase the supply of capital and the share of heavily polluting products. The industry structure effect of FDI may be positive on pollution intensity. However, we take a different view according to the sample analysis. Figure 1 shows that the average of firms' foreign equity shares increased substantially in both heavily and lightly polluting industries,[2] which increased from 12.88 to 21.35 per cent in lightly polluting industry and from 7.17 to 11.96 per cent in heavily polluting industry. Foreign equity shares of firms in lightly polluting industries increased more significantly.

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[2] The Ministry of Environmental Protection (MEP) determines 16 heavily polluting industries, including thermal power, iron and steel, cement, electrolytic aluminum, coal, metallurgy, chemical, petrochemical, building materials, paper, brewing, pharmaceutical, fermentation, textile, tanning, and mining. Other industries are lightly polluting industries.

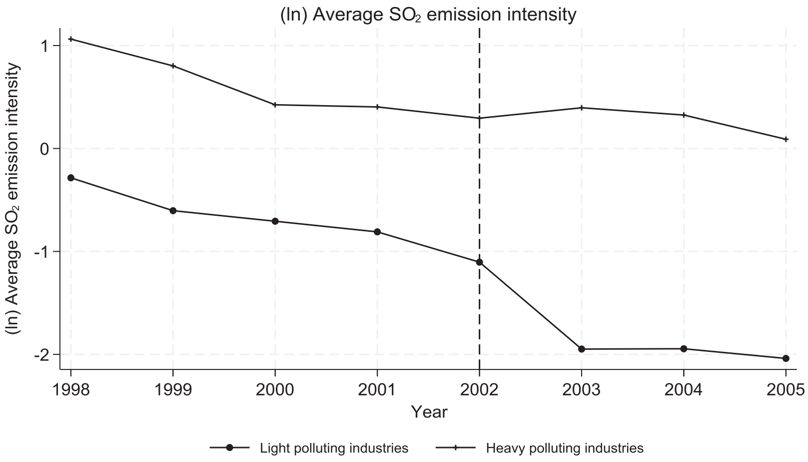

Figure 2. Pollution intensities of lightly and heavily polluting industries.

Meanwhile, the output share of foreign firms in lightly polluting industries also increased more significantly. The foreign firms' output share in heavily polluting industries grew slowly from 22.86 to 25.79 per cent, while that in lightly polluting industries grew from 23.69 to 46.13 per cent, nearly doubling. Foreign firms may lead to massive growth in lightly polluting industries. Skewing the production to non-polluting products results in a cleaner output industry structure.

We further provide a figure with trends of the average SO_2 emission intensity of firms in lightly and heavily polluting industries. Figure 2 shows that the average SO_2 emission intensities of firms in lightly and heavily polluting industries are gradually decreasing. In the heavily polluting industries, the downward trend is consistently smooth. Conversely, the lightly polluting industries experienced a pronounced and substantial decline after 2002. Figure 2 is consistent with the previous analysis in figure 1. The industry structure effect of FDI may be negative (on pollution intensity).

In summary, we put forward the following hypothesis. FDI may reduce the pollution intensity of firms in host countries by increasing productivity, pollution management abilities, and the output share of non-polluting industries.

3. Empirical framework

3.1 Shocks of FDI access relaxation

Following Lu *et al.* (2017), we introduce the FDI access relaxation in 2002 as an exogenous shock to identify the effect of FDI. China first promulgated the Catalogue for the Guidance of Foreign Investment Industries (henceforth, the Catalogue) in 1995, then the Catalogue became the most important guideline for FDI in China. It went through several revisions in the next years. This study focuses on the revision in 2002 to investigate the impacts of FDI inflows on firms' pollution intensity from 1998 to 2007. It is important to investigate the environmental effect of FDI in China for this period. On the one hand, China attracted a large amount of FDI and experienced rapid industrialization during this period, accompanied by severe environmental degradation. On the other hand, the FDI access relaxation policy provides a good opportunity to deal with the endogeneity problem. The revision of the 2002 Catalogue is mainly based on China's commitments to WTO member countries. Therefore, it is plausibly exogenous to China's domestic economy.

The Catalogue classified the FDI regulations of products into four categories: 'Encouraged,' 'Permitted,' 'Restricted' and 'Prohibited.' In March 2002, China made substantial revisions to the Catalogue by revising a large number of products in 'Restricted' or 'Prohibited' categories to 'Encouraged' or 'Permitted' categories, relaxing the restrictions on FDI. We convert the products in the Catalogue into the four-digit industry and find each industry may experience four types of changes including 'FDI encouraged,' 'FDI discouraged,' 'No change,' and 'Mixed change' from 1997 to 2002. Following Lu *et al.* (2017), the firms in the 'FDI encouraged' group, which experienced large inflows of FDI after 2002, serve as the treatment group, and the firms in the 'No change' group are the control group.

3.2 Empirical model

To identify the effects of FDI on firms' pollution intensity, we use a DID methodology to overcome the estimation bias, as shown in equation (2):

$$\ln E_{it} = \beta_0 + \beta_i Treat_i \times Post_t + \beta_2 Control_{it} + \delta_i + \gamma_t + \varepsilon_{it}, \tag{2}$$

where i denotes the firm and t indicates the year. This model contains firm-fixed effects δ_i and year-fixed effects γ_t. ε_{it} is the error term. Standard errors are clustered at the firm level to deal with the potential serial correlation and heteroscedasticity problem. The natural logarithm of firms' pollution intensity is the dependent variable ($\ln E_{it}$) in the baseline examination. And the pollution intensity is measured by the ratio of SO_2 emissions to firms' output. The dummy variable $Treat_i$ indicates whether firm i belongs to the 'FDI encouraged' group, which serves as the treatment group. The dummy variable $Post_t$ equals one if $t \geq 2002$. Otherwise, it equals 0. The interaction $Treat \times Post$ is the core explanatory variable.

We introduce a vector of control variables, including the firms' size, age, productivity, and capital-labor ratio. The definitions of variables are in panel A of table 1.

ln*size* measures firm size. Copeland and Taylor (2004) argued that firms' pollution emissions are proportional to their size with constant returns to scale and the same product mix and production technology. Thus, firm size is an important influencing factor for emissions.

ln*age* measures firms' age. Aging is accompanied by firms' expansion and knowledge accumulation, helping to improve resource use efficiency and reduce pollution. Older firms have incentives to make abatement investments for reputation. However, their production equipment and technology are also aging. Therefore, it is necessary to control firms' age.

ln*kl* denotes the natural logarithm of the capital-labor ratio. Copeland and Taylor (2004) assume that pollution-intensive industries are capital-intensive, and the capital-labor ratio has a positive influence on emissions. However, some studies suggest that firms with higher capital-labor ratios have sufficient financial support to invest in green innovation, which reduces pollution emissions (Berrone *et al.*, 2013; Cai *et al.*, 2020).

ln*tfp* denotes firms' productivity. Firms with higher productivity produce fewer pollutants with the same output (Wang and Zhu, 2021). We expect a negative effect of ln*tfp* on firms' pollution intensity.

Table 1. Definitions and descriptive statistics of variables

Panel A. Definitions of variables

Variable	Definition
E	Ratio of SO_2 emissions to firms' output. We use its logarithm ($\ln E$) in the regression.
$Treat_i$	$Treat_i = 1$ if firm i belongs to the treatment group; otherwise, 0.
$Post_t$	Time dummy variable; $Post_t = 1$ if $t \geq 2002$; otherwise, 0.
size	Revenue. We use its logarithm ($\ln size$) in the regression.
age	Age. We use its logarithm ($\ln age$) in the regression.
kl	Capital-labor ratio. We use its logarithm ($\ln kl$) in the regression.
tfp	Following Olley and Pakes (1996). We use its logarithm ($\ln tfp$) in the regression.

Panel B. Descriptive statistics of variables

Variables	Unit	Mean	Median	S.D.	Min	Max
E	Kilogram/Thousand Yuan	2.067	0.330	5.417	0.000	43.228
Treat	–	0.285	0		0	1
Post	–	0.769	1		0	1
size	Thousand Yuan	177,385.627	35,211.500	1,098,647.457	1	125,600,000
age	Year	15.998	10	14.685	1	64
kl	Thousand Yuan per worker	109.891	58.556	159.331	1.749	1,051.408
tfp	–	6.670	6.649	1.031	3.927	9.276

Notes: This table presents definitions and summary statistics of the variables. The sample is composed of 185,924 observations.

The summary statistics of the main variables are provided in panel B of table 1. The sample is composed of 185,924 observations. For the dummy variable *Treat*, indicating whether the firm is affected by the policy, the mean value is 0.285. Therefore, 28.5 per cent of the firms in the sample belong to the 'FDI encouraged' group.

We perform a parallel-trend test and a placebo test to ensure the results' validity. Then the robustness checks are conducted to ensure the credibility of the estimation. This study explores three influencing mechanisms of FDI on firms' pollution intensity and further tests the potential heterogeneity amongst the observations.

3.3 Datasets

This study combines two datasets, described below, that provide comprehensive information on the production and emissions of firms in China.

Annual Survey of Industrial Firms (ASIF). The ASIF provides the production information from 1998 to 2007, such as the sales, fixed assets, ownership structure, identification number, and employment of firms with annual sales exceeding 5 million RMB. Following Brandt *et al.* (2012), we link the firms over the years. Firms with less than eight employees and with missing or negative paid-in capital are excluded from the database.

Table 2. Baseline results

	ln *E*	
	(1)	(2)
Treat × *Post*	−0.155 (0.036)	−0.120 (0.036)
ln *size*		−0.047 (0.023)
ln *age*		0.066 (0.017)
ln *kl*		−0.149 (0.014)
ln *tfp*		−4.387 (0.159)
Firm FE	Yes	Yes
Year FE	Yes	Yes
N	165,165	165,165
adj. R^2	0.801	0.806

Notes: This table presents the impact of FDI on firms' pollution intensity in China. Both regressions include the firm- and year-fixed effects. Standard errors are clustered at the firm level and reported in parentheses.

Chinese Enterprise Environmental Survey and Reporting Database (ESR). The ESR is conducted by the MEP, providing comprehensive environmental data on polluting sources in China. The database includes the sources of the top 85 per cent of the pollution emissions in a county. Each pollution source self-reports to the MEP and then is verified randomly. The polluters have little incentive to misrepresent the data, as the law stipulates that the ESR cannot be used as a basis for pollution regulation and punishment, ensuring the quality of the data (He *et al*., 2020).

We match the ASIF and ESR in two steps. The first step uses firms' identification numbers as the matching keyword, and the second step uses firms' names to identify the remaining samples. We use SO_2 emissions to calculate the pollution intensity as the dependent variable in the baseline examination. The firms with missing SO_2 emissions are dropped based on the matched data. The final sample is composed of 185,924 observations from 1998 to 2007.

4. Empirical results

4.1 Baseline results

The baseline results are presented in table 2. Whether we include the control variables or not, the coefficients of *Treat* × *Post*, which measure the impact of FDI on firms' pollution intensity, are negative and significant at the 1 per cent level. According to column (2), the pollution intensity of the firms drops by 12 per cent. The results imply a positive impact of FDI inflows on China's environment, suggesting that FDI has a 'pollution halo' effect. We will further examine the validity and robustness of the results in the following subsections.

Table 3. Dynamic effects of FDI inflows

	$\ln E$ (1)
$Treat \times D_{1998}$	0.068 (0.075)
$Treat \times D_{1999}$	0.001 (0.067)
$Treat \times D_{2000}$	−0.094 (0.059)
$Treat \times D_{2002}$	0.008 (0.043)
$Treat \times D_{2003}$	−0.092 (0.046)
$Treat \times D_{2004}$	−0.179 (0.049)
$Treat \times D_{2005}$	−0.234 (0.053)
$Treat \times D_{2006}$	−0.239 (0.052)
$Treat \times D_{2007}$	−0.246 (0.053)
Controls	Yes
Firm FE	Yes
Year FE	Yes
N	165,165
$adj.\ R^2$	0.806

Notes: This table presents the dynamic effect of FDI. D_t is the time dummy variable. It equals 1 in year t and 0 otherwise. The regression includes the firm- and year-fixed effects. Standard errors are clustered at the firm level and reported in parentheses.

4.2 Parallel-trend test

We conduct a dynamic estimation to explore whether the firms in the treatment group and control group experienced a parallel trend before the relaxation of FDI access in 2002. We add the interactions of *Treat* and time dummy variables D_t to augment equation (2). The regression model for the parallel-trend test is

$$\ln E_{it} = \beta_0 + \sum_{t=1998}^{2007} \beta_t \times Treat_i \times D_t + \beta_2 Control_{it} + \delta_i + \gamma_t + \varepsilon_{it}, \qquad (3)$$

where D_t equals 1 for observations in year t and 0 if not. For example, D_{1998} is 1 for observations in 1998 and 0 otherwise. The omitted year is 2001. The interactions can trace the firms' responses in the treatment group versus those in the control group over time. This model also includes the firm- and year-fixed effects.

As shown in table 3, the coefficients of the interactions before 2002 are insignificant, indicating that the firms in the treatment group are not significantly different from those in the control group in terms of pollution intensity before the FDI access relaxation. The parallel trend assumption required for the DID approach is verified.

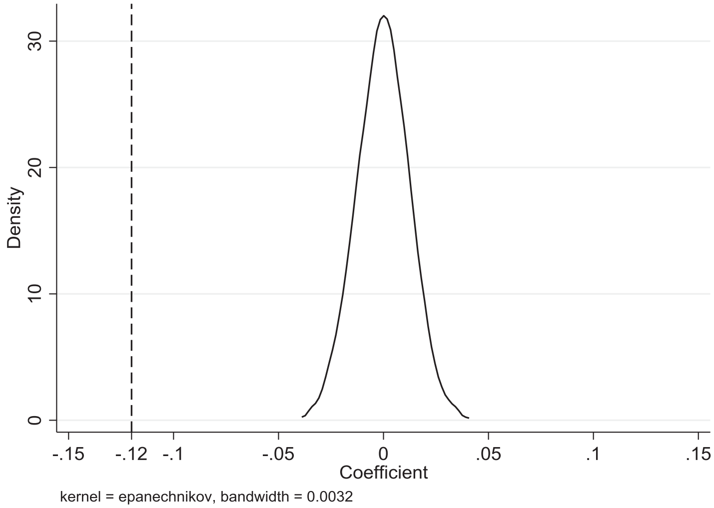

Figure 3. Placebo test.
Note: This figure reports the distribution of the coefficients of *fTreat* × *Post* in the placebo test.

4.3 Placebo test

The DID approach can be used when the treatment group is selected randomly. The results may be biased if the treatment group is selected according to some unobservable factors. This subsection employs a placebo test to address this concern. We construct a false interaction *fTreat* × *Post* for the placebo test by randomly generating the selected firms. The false interaction should have no significant effect on pollution intensity. We repeat the regression with *fTreat* × *Post* randomly generated 500 times and plot the coefficients in figure 3. The coefficients' mean value is 0 and the coefficient in the baseline finding (−0.120) is a clear outlier, indicating that the baseline results are not driven by unobservable factors.

4.4 Robustness checks

This section provides the robustness checks on the baseline results in the following subsections when (a) employing an IV-2SLS method, (b) excluding the effects of the environmental regulations in the 11FYP, (c) excluding the effects of other environmental regulations, (d) extending the timeframe to 2011, (e) excluding the effects of other economic policy reforms, and (f) using other pollutants to measure pollution intensity.

4.4.1 Instrumental variable approach

In the benchmark analysis, we rely on a DID identification strategy to investigate the effects of the FDI liberalization policy, since the policy is exogenous and captures the FDI inflows. However, other factors may also impact the inflows of FDI. Therefore, we construct the presence of FDI following Javorcik (2004) as the core independent variable and employ an IV-2SLS method to complement our baseline analysis. The presence of FDI in industry *j* is

$$fdi\_sector_j = \frac{\sum_{i \in j} fdi\_share_i \times output_i}{\sum_{i \in j} output_i} \tag{4}$$

where *fdi_share* is the share of foreign equity in firm *i* and *output* is the output of firm *i*. We take interaction *Treat* × *Post* as an instrumental variable. Column (1) in panel A of table 4 reports the first step estimation result and reveals a significant positive correlation between the instrumental variable and *fdi_sector*, indicating that the FDI access relaxation policy increases the inflows of FDI. The underidentification and weak identification tests suggest that the instrument is valid. Column (2) reports the second step estimation result and confirms the negative and significant impacts of FDI on pollution intensity. Our results are robust.

4.4.2 Effects of the eleventh five-year plan

China proposed energy conservation and emission reduction in the 11FYP from 2006 to 2010. To check whether the main results are biased due to the energy conservation and emission reduction policies, we re-run the baseline examination with the exclusion of the environmental policies in this period.

First, we exclude the samples in 2006 and 2007. As shown in column (3) in panel A of table 4, the results still present a significantly negative effect of FDI on pollution intensity. The 11FYP is not the main driver of the baseline results.

Second, the 11FYP requires strengthening the management of energy conservation and emission reduction in key manufacturing industries including iron and steel, nonferrous metals, petroleum and petrochemicals, chemicals, and building materials.[3] We exclude the firms belonging to the key industries from the sample and re-run the baseline test. The results are still robust as shown in column (4) in panel A of table 4.

Third, the 11FYP includes an important emission reduction policy implemented at the firm level, the Top 1000 Enterprises Energy-Conservation Program (T1000P). The T1000P, which came into effect in 2006, selected 1,008 firms with a combined energy consumption of 180,000 tons of standard coal or more in 2004. The total energy consumption of the 1,008 firms accounts for 33 per cent of the total national energy consumption and 47 per cent of the industrial energy consumption. Local governments set abatement targets through negotiations with the firms and provide financial support (Price *et al*., 2010). We exclude the firms in the T1000P to alleviate the concern that the main findings are driven by the T1000P. In column (5) in panel A of table 4, the result suggests that the T1000P is not our findings' main driver.

4.4.3 Effects of other environmental regulations

In addition to the policies in the 11FYP, other environmental regulations may also impact our results. China has implemented a wide range of environmental regulations during the sample period due to increasing environmental concerns. Acid rain and SO_2 control zones were officially designated in 1998. China's central government started introducing water quality indicators to the evaluation system for political promotion in 2003 and then introduced the abatement indicators of Chemical Oxygen Demand and SO_2 into the system in 2006 (Kahn *et al*., 2015; Bao *et al*., 2021; Liu and Kong, 2021; Tian and Tian, 2021; Kong *et al*., 2022*b*).

We exclude the impacts by controlling for fixed effects at a range of policy implementation levels since most environmental policies in China are implemented on an administrative zoning basis. Acid rain and SO_2 control zones are city-based. The

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[3] Notice of the State Council on Further Intensifying Efforts to Ensure the Achievement of the Eleventh Five-Year Energy Conservation and Emission Reduction Goals.

Table 4. Robustness checks

Panel A	*fdi_sector*	ln*E*	ln*E*				
	IV-2SLS		11FYP			City-year FE	Industry-city FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treat × *Post*	0.011 (0.002)		−0.113 (0.038)	−0.150 (0.049)	−0.120 (0.036)	−0.095 (0.036)	−0.134 (0.038)
fdi_sector		−10.864 (3.777)					
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes		Yes
City-year FE						Yes	
Industry-city FE							Yes
N	165,165	165,165	115,555	112,536	162,714	164,808	164,551
adj. R^2			0.821	0.821	0.807	0.814	0.801

Panel B	ln*E*			ln*E_water*	ln*E_COD*	ln*E_nh*	ln*E_dust*
	Timeframe	SOEs	Tariff	Other pollutants			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treat2 × *Post2*	−0.111 (0.029)						
Treat × *Post*		−0.117 (0.036)	−0.166 (0.039)	−0.032 (0.009)	−0.062 (0.009)	−0.137 (0.082)	−0.172 (0.082)
state_share		0.020 (0.041)					
ftariff × *Post*			0.006 (0.003)				
itariff × *Post*			−0.023 (0.006)				
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	201,911	164,112	143,607	155,660	153,410	113,065	29,736
adj. R^2	0.792	0.806	0.811	0.836	0.765	0.626	0.866

Notes: This table presents the robustness checks. In panel A, columns (1)–(2) use the IV-2SLS approach. The Kleibergen-Paap Wald F statistic is 33.740 and the Kleibergen-Paap LM statistic is 33.553. Columns (3)–(5) exclude the environmental policies in the 11FYP. Columns (6)–(7) condition out the influences of the other environmental regulations by controlling for fixed effects at the levels of policy implementations. In panel B, column (1) extends the timeframe to 2011. Columns (3)–(4) condition out the impacts of the restructuring of SOEs in the early 2000s and tariff reduction after China's WTO accession. Columns (5)–(7) use other pollution emissions to measure the pollution intensity. Standard errors are clustered at the firm level and reported in parentheses.

environmental indicators introduced into the evaluation system are based on the responsibility contracts between the central and local governments.

Column (6) in panel A of table 4 show the results of including the city-year-fixed effect. We continue to find the reduction of pollution intensity after the FDI access relaxation. Furthermore, some environmental policies may vary across industries. Therefore, we add the industry-city-fixed effect to the baseline results in column (7) in panel A of table 4. The negative effects on pollution intensity continue to hold.

4.4.4 Extending the timeframe to 2011

This subsection extends the timeframe to 2011 to improve the application of our findings' implications.[4] The Catalogue went through several revisions after its promulgation in 1995. The baseline examination uses the 2002 revision to identify the effect of FDI. This subsection uses multi-period policy impact, including the revisions in both 2002 and 2007, to identify the effect of FDI on firms' pollution intensity. Firms that experienced FDI access relaxation in either 2002 or 2007 serve as the treatment group, and firms with unchanged FDI regulations are the control group. We use the interaction of $Treat2_i$ and $Post2_{it}$ to replace $Treat \times Post$ in the baseline model. $Treat2_i$ equals 1 if firm i belongs to the 'FDI encouraged' group in either the 2002 or 2007 revision and 0 otherwise. $Post2_{it}$ equals 1 after the firm experienced FDI access relaxation (including the current year) and 0 otherwise. We present the result in column (1) in panel B of table 4. The coefficient of the interaction is significantly negative. The reduction effects on firms' pollution intensity continue to hold.

4.4.5 Effects of other economic policy reforms

Another crucial issue is that other economic policies around 2002 in China may impact our results, making the estimates of the FDI effects biased. Two important economic reforms are the restructuring of state-owned enterprises (SOEs) and import tariff reduction after China's WTO accession. To condition out the impacts of SOE restructuring, we add the share of state-owned capital in paid-in capital (*state_share*) into the control variables. The results are presented in column (2) in panel B of table 4, and the negative effects of FDI on firms' pollution intensity continue to hold.

To condition out the effect of the import tariff reduction after 2001, we use the tariffs in 2001 as the proxy variable for tariff reduction since the industries with higher tariffs in 2001 experienced a more significant tariff reduction after WTO accession (Lu and Yu, 2015). We add the interaction of intermediate goods' import tariffs (*itariff*) and *Post* and the interaction of final goods' import tariffs (*ftariff*) and *Post* to the control variables. The result reported in column (3) in panel B of table 4 remains consistent with our baseline results.

4.4.6 Pollution intensity based on other pollutants

We use the ratio of SO_2 emissions to output to proxy pollution intensity in the baseline model. This subsection uses other pollutant emissions to construct the dependent variables as robustness checks. Specifically, we calculate the emission intensities of industrial wastewater ($\ln E\_water$), chemical oxygen demand ($\ln E\_COD$), ammonia nitrogen

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[4] Some variables used in robustness and mechanism tests between 2008 and 2011 are missing in the database, such as *state_share*, ln*coal*, ln*oil*, and ln*gas*. Therefore, our baseline regression focuses on the samples from 1998 to 2007.

($\ln E\_nh$), and industrial dust ($\ln E\_dust$), and adopt them as the main dependent variables, respectively. Columns (4) to (7) in panel B of table 4 provide the results. All the estimated coefficients are significantly negative, indicating that the main findings are robust.

4.5 Mechanisms

This section explores the potential influencing mechanisms. As analyzed in section 2, FDI may affect the firms' pollution intensity through productivity, pollution management, and industry structure effects.

4.5.1 Productivity effect

This subsection examines the productivity effect. The coefficient in column (1) in panel A of table 5 is negative and significant at the 10 per cent level. However, both the magnitude and significance of the estimated coefficient suggest a weak productivity effect. Moreover, the analysis in section 2 shows that FDI was a greater growth driver for lightly polluting industries. We are concerned that this result may be due to the heterogeneity among firms in polluting and lightly polluting industries. Therefore, we examine productivity effects for firms in lightly and heavily polluting industries separately. Column (2) in panel A of table 5 shows that the impact of FDI on firm productivity in heavily polluting industries is insignificant, while column (3) in panel A of table 5 indicates that FDI significantly increases firm productivity in lightly polluting industries. The negative effect of FDI on firms' pollution intensity through improving productivity is evidenced only in lightly polluting industries.

This finding is inconsistent with the argument that FDI is attracted to heavily polluting industries in developing countries because of their lax environmental regulations. We explain the finding by analyzing the determinants of China's FDI inflows. The pollution abatement cost may be part of the reason, but not a determinant, for international capital flows. The factor endowments also play an important role, which seems to have the opposite result with the pollution haven hypothesis (Cole and Elliott, 2005). According to factor endowment theory, FDI is more likely to invest in China's lightly polluting industries, which are usually labor-intensive industries, following the comparative advantage with abundant labor. Many studies confirm the attraction of labor to FDI while finding no evidence that high pollution abatement costs in developed countries drive the transaction of the polluting production to the developing countries and that the developing countries care less about the environment (Cole and Elliott, 2005; Zhang, 2005; Dean *et al.*, 2009; Cai *et al.*, 2016).

China adopted a strategy of prioritizing heavy industry for over 30 years after the reform and opening up, which is inconsistent with its comparative advantage. A huge amount of domestic investment flows into heavy industries (Zhao *et al.*, 2016; Liu *et al.*, 2017). In contrast, light industries dominated by labor-intensive small and medium enterprises are facing capital constraints (Beck *et al.*, 2008; Chong *et al.*, 2013). Although capital requirements are lower in labor-intensive industries, they still require a stage or threshold of the capital intensity (Cole and Elliott, 2005). FDI inflows can alleviate their financing constraints and increase the productivity of these firms.

4.5.2 Pollution management effect

As mentioned in section 2, firms manage pollution through two channels: changing energy structure and endpoint pollutant management. Therefore, we investigate how

Table 5. Mechanisms

Panel A	ln*tfp*			ln*coal*	ln*oil*	ln*gas*	ln*rate*	ln*size*	
		Heavily polluting	Lightly polluting					Heavily polluting	Lightly polluting
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treat × *Post*	0.001 (0.001)	0.001 (0.001)	0.003 (0.001)	−0.157 (0.030)	0.083 (0.020)	0.018 (0.014)	0.008 (0.023)	0.009 (0.008)	0.022 (0.011)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	165,165	99,799	64,314	156,880	130,036	96,013	111,237	99,799	64,314
adj. R^2	0.934	0.929	0.940	0.803	0.813	0.676	0.611	0.959	0.963
Panel B	ln*coal*	ln*oil*	ln*gas*	ln*rate*	ln*coal*	ln*oil*	ln*gas*	ln*rate*	
	Heavily polluting				Lightly polluting				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
Treat × *Post*	−0.042 (0.040)	0.118 (0.026)	−0.020 (0.019)	0.031 (0.028)	−0.388 (0.051)	0.048 (0.034)	0.050 (0.022)	−0.038 (0.042)	
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
N	94,141	76,251	57,204	72,071	61,717	52,802	37,890	38,378	
adj. R^2	0.765	0.823	0.700	0.603	0.851	0.801	0.636	0.630	

Notes: This table presents the mechanisms through which FDI influences firms' pollution intensity. All the control variables are defined in table 1, except that ln*tfp* is excluded from the control variables in columns (1)–(3) of panel A, and ln*size* is excluded from the control variables in columns (8)–(9) of panel A. The regressions include the firm- and year-fixed effects. Standard errors are clustered at the firm level and reported in parentheses.

FDI impacts firms' pollution intensity through these two channels. Specifically, we first estimate the effect of FDI on firms' use of different types of energy, including coal, oil, and gas. The results are presented in columns (4)–(6) in panel A of table 5. The use of coal (ln*coal*) experiences a drop, and the use of oil (ln*oil*) increases simultaneously, indicating that firms tend to change their energy structure after the FDI access relaxation. The effect on gas use (ln*gas*) is insignificant. This finding suggests that FDI changes the energy use structure to reduce pollution in host countries, supporting the pollution halo hypothesis.

Then we estimate the channel of endpoint pollutant management by regressing the SO_2 reduction rate (ln*rate*). As shown in column (7) in panel A of table 5, the coefficient is insignificant, indicating that FDI does not improve the firms' endpoint pollutant management. Therefore, the pollution management effect of FDI is mainly through changing the energy structure rather than the endpoint pollutant management.

In addition, we investigate the effects of FDI on energy use and endpoint pollutant management of firms in polluting and lightly polluting industries respectively to discuss the mechanisms in more detail. The results are shown in panel B of table 5. Columns (1)–(4) are the results of firms in heavy pollution industries, showing that FDI significantly increases the use of oil. Columns (5)–(8) are the results of firms in lightly polluting industries, suggesting that FDI significantly reduces the use of coal and increases the use of gas. Both results on SO_2 reduction rate (ln*rate*) are insignificant. The results further indicate that FDI enhances firms' pollution management by changing the energy structure.

4.5.3 Industry structure effect

The industry structure effect of FDI depends on its impact on the share of heavily and lightly polluting industries. We investigate the industry structure effect by comparing the impact of FDI in guiding the production of heavily and lightly polluting industries. If FDI is conducive to the production of heavily polluting goods, firms in heavily polluting industries will expand their output scale. The industry structure effect will increase pollution intensity. Conversely, if FDI skews the production to lightly polluting products, firms in lightly polluting industries will expand their scale and the industry structure effect will decrease pollution intensity.

We use the revenue to measure firms' output scale and investigate the impact of FDI on the scale of firms in heavily and lightly polluting industries, respectively. Column (8) in panel A of table 5 shows that FDI has no significant effect on the firm scale in heavily polluting industries and column (9) in panel A of table 5 shows that FDI can significantly increase firms' scale in lightly polluting industries, suggesting that FDI skews the production to lightly polluting products, and has a negative industry structure effect on pollution intensity.

4.6 Heterogeneity

4.6.1 Different industry types

Considering that firms in lightly and heavily polluting industries may have different responses to shocks, we investigate the heterogeneous effect of FDI on firms' pollution intensity in lightly and heavily polluting industries (Kong and Qin, 2021). The results in columns (1) and (2) of table 6 show that the negative effect of FDI on firms' pollution intensity in lightly polluting industries is detected, while the firms in heavily polluting industries are not responsive to FDI.

Table 6. Heterogeneity

	ln *E*						
	Industry types		Ownership		Regions		
	Lightly polluting	Heavily polluting	Domestic	Foreign	East	Central	West
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treat × *Post*	−0.439	0.024	−0.098	−0.142	−0.138	−0.115	−0.070
	(0.064)	(0.045)	(0.039)	(0.089)	(0.047)	(0.070)	(0.083)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	*Yes*
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	64,314	99,799	133,557	30,848	96,897	34,361	33,903
adj. R^2	0.813	0.762	0.779	0.841	0.817	0.767	0.770

Notes: This table studies the heterogeneous effects of FDI on firms' pollution intensity. The regressions include the firm- and year-fixed effects. Standard errors are clustered at the firm level and reported in parentheses.

4.6.2 Different ownerships

Ownership plays a vital role in firms' performance and scholars suggest that firms with different ownerships have different responses to FDI inflows (Lu *et al.*, 2017; Zhang *et al.*, 2019). We classify the firms into domestic and foreign firms and investigate whether the impact of FDI varies between the two groups. As shown in columns (3)–(4) of table 6, the estimator for the interaction of domestic firms is negative and significant, while the estimator of the foreign firms is not as significant as expected. FDI inflows reduce the pollution intensity of domestic firms, indicating that foreign firms may improve domestic firms' environmental awareness and technology through technology transfer, labor turnover, and demonstration effects (Hille *et al.*, 2019; Kong *et al.*, 2020).

4.6.3 Different regions

Considering the regional development imbalance in China, we investigate the heterogeneous impacts of FDI on firms' pollution intensity in different regions. We divide the sample into firms from eastern, central, and western regions, and re-estimate the baseline results. The results in columns (5)–(7) of table 6 indicate that only the impact on the eastern firms is significant and negative. The eastern region has a large concentration of labor-intensive industries and attracts a larger share of FDI in China. FDI improves firms' productivity in lightly polluting industries, which are usually labor-intensive industries, so the pollution intensity reduction effect of FDI in the eastern region is larger than that in other regions.

5. Conclusion and policy implications

This study explores the causal relationship between FDI and firms' pollution intensity by exploiting the policy of China's FDI access relaxation in 2002. Relying on the panel data from 1998 to 2007, we find that FDI significantly reduces firms' pollution intensity in China. The mechanism tests show that FDI reduces firms' pollution intensity by increasing productivity, pollution management abilities, and the share of lightly polluting industries. The pollution intensity reduction effects of FDI mainly act on firms in lightly polluting industries and firms in the eastern region. Overall, this study re-examines the relationship between FDI and host countries' environment from a micro perspective and confirms the pollution halo effect.

Our findings offer crucial insights into the strategies that emerging markets can employ to realize environmentally sustainable development through FDI. First, in following the comparative advantages of host countries, FDI has been proven to be effective in reducing the pollution intensity of manufacturing firms, providing strong support for the green development of host countries, and especially helping to improve the environmental performance of domestic firms. Therefore, developing countries should actively attract FDI and provide it with the necessary policy support and facilitation. They should also formulate appropriate FDI attraction policies based on their resources and industrial advantages. In addition, it is also necessary to strengthen the communication and collaboration between domestic and foreign firms, to enhance the environmental awareness and capability of domestic firms and promote the wide application of green technologies.

Second, our study also highlights industrial restructuring as an important way for FDI to exert its influence. Nevertheless, it is important to note that FDI has a limited impact on heavily polluting industries, and is only effective in optimizing the energy structure of heavily polluting firms, with minimal effects on productivity gains. Therefore, reducing emissions from heavily polluting industries should not depend solely on the introduction of FDI. Developing countries need to take other measures to improve the environmental performance of firms in these industries, ensuring a harmonious balance between economic growth and environmental preservation.

Future research may further our study in two ways. First, due to data availability, we focus on the manufacturing industry, which has the positive implication that we focus on pollution in the production process. However, we may underestimate the pollution abatement of industry structure effect by promoting the growth of the service. Second, we focus on the effect of FDI on firms' pollution intensity. The results help to accurately evaluate the aggregate role of FDI compared with the role of domestic investment in the environment.

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