Trade barrier decrease and environmental pollution improvement: new evidence from China’s firm-level pollution data

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Abstract

Purpose – Trade and environment are essential issues closely related to the development of the national economy and the improvement of people’s livelihood in the new era. The Report to the 19th National Congress of the Communist Party of China (CPC) listed the construction of a strong trading power as an important part of building a modern economic system and pollution prevention and treatment as one of the three key battles to win the decisive victory of building a moderately prosperous society in all respects. However, the relationship between trade and environmental pollution is still very controversial in the existing literature, and there is a paucity of literature on the relationship between trade and environmental pollution based on micro data.

Design/methodology/approach – This paper merged China’s Firm-Level Pollution Database with China’s Industrial Enterprise Database and China’s industry tariff rates. Additionally, by virtue of the quasi-natural experiment of China’s accession to the World Trade Organization (WTO), a difference in difference (DID) model was constructed to alleviate the endogeneity issue.

Findings – According to the results, the trade barrier decrease (trade liberalization) significantly reduces the intensity of SO_2 emissions, a major pollutant of enterprises, as the intensity of SO_2 emissions decreased 2.16% for each unit decrease of the trade barrier. The analysis of the mechanisms shows that the SO_2 emission intensity of enterprises is mainly due to the decrease of enterprises’ pollution emission rather than the decrease of output, and the decrease of enterprises’ pollution emission is mainly caused by the enterprises’ cleaner production process rather than the end treatment of pollution emission. The decrease of coal use intensity is an important mechanism of the decrease of SO_2 emission intensity caused by the decrease of trade barriers. Among the technical effects of the change of the trade barrier affecting enterprises’ pollution emission, biased technical change rather than neutral technical change dominates.

Originality/value – The findings of this paper imply that expanding openness can enhance China’s social welfare not only through the economic growth mechanisms identified in the classical literature, but also through environmental improvements. This provides useful policy insights for promoting the construction of a strong trading power and winning the battle against pollution in the new era.

Keywords Trade, Environmental pollution, China’s firm-level pollution database

Paper type Research paper

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1. Introduction

Trade and environment are essential issues closely related to the development of the national economy and the improvement of people's livelihood in China. Promoting the construction of strong trading power and pollution prevention and treatment are strategic initiatives of Communist Party of China (CPC) and the government for governance in the new era. With the miracle of economic growth through reform and opening-up, especially after accession to the World Trade Organization (WTO), China had seen a spurt of development in its import and export trade. In 2013, China overtook the United States as the world's largest trading country. China steadfastly expands its openness, facing the instability and uncertainty of current world trade patterns. In particular, the Report to the 19th National Congress of the CPC includes promoting the construction of a trading power as an essential part of building the modernized economic system. The *Proposal of the Central Committee of the Chinese Communist Party on Drawing Up the 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2030* further specified the need to promote dual circulations of the domestic and international economy, synergize the construction of a robust domestic market and trading power and fully leverage both domestic and international markets and resources. Meanwhile, as the living standard continues to improve, people have higher requirements for environmental quality, which is increasingly contradictory to the problem of environmental pollution in economic development. To meet the people's growing demand for a better life, the CPC and the government need to provide a sound ecological environment while raising people's income level by boosting economic growth. In this context, the CPC and the state have elevated environmental governance to an unprecedented level. The Eighteenth National Congress placed the construction of ecological civilization in a strategic position in the overall plan for the development of socialism with Chinese characteristics, "encompassing five areas" (economic, political, cultural, social and ecological development). The Report to the 19th National Congress of CPC further listed pollution prevention and treatment as one of the three challenging tasks to secure a decisive victory in building a moderately prosperous society in all respects.

A crucial question closely related to the above practical and policy context but yet to be investigated thoroughly is the link between trade and environmental pollution in China. In other words, does trade have a significant impact on environmental pollution in China? If so, is this impact positive or negative? More importantly, what are the mechanisms involved? Exploring these questions systematically, especially identifying the causal relationships among them, has essential policy insights for promoting the construction of a strong trading power and winning the tough battle against pollution. These are the questions that this paper focuses on. Specifically, this paper investigates the questions with a normative causal identification strategy based on a unique and comprehensive firm-level database using China's accession to the WTO as a quasi-natural experiment. In addition to the realistic policy insights, exploring the relationship between trade and environmental pollution has important theoretical significance. Literature on classical trade economics indicates that trade can drive economic growth through channels such as comparative advantage, increasing returns to scale and resource reallocation among heterogeneous firms to affect the welfare levels of trade participants. If the trade has a significant impact on environmental pollution, it can affect the level of social welfare through changing the environment, in addition to the economic growth mechanisms identified by classical literature.

The remaining content of the paper is structured as follows: Section 2 provides a review of the existing relevant literature and indicates the contribution of this paper to research innovation; Section 3 introduces the data and identification strategy; Section 4 reports the main empirical results on the impact of trade on environmental pollution; Section 5 is the mechanism analysis; Section 6 provides an extended discussion, and Section 7 is the conclusion.

2. Literature review and research innovation

Regarding the relationship between trade and environmental pollution, a branch of literature indicates that a "pollution haven" effect exists; that is, trade can lead to the relocation of polluting industries from developed countries with more stringent environmental regulations to developing countries with less stringent environmental regulations, thus causing ecological degradation in the latter. Based on cross-country data, Lucas *et al.* (1992) found that the continuous relocation of polluting industries to developing countries worldwide exacerbated the environmental pollution in these countries. Zhang (2009) pointed out that the impact of trade on China's energy consumption and pollution emissions could no longer be ignored, and the scale effect of the rapid growth in exports led to a sharp rise in the energy and sulfur content of China's exports between 1987 and 2006. A study by Li and Qi (2011) showed that trade opening increased the emission of CO_2 and the carbon intensity in Chinese provinces and regions.

Different from the "pollution haven hypothesis," which suggests that trade exacerbates environmental pollution in developing countries, another branch of literature argues that trade significantly reduces environmental pollution in developing countries through technical or allocative effects. The study by Li and Lu (2010) is a representative example. They examined the impact of international trade on China's industrial CO_2 emissions based on industry data and found that trade ultimately reduced total industrial CO_2 emissions by lowering CO_2 emissions per unit of output and that China did not become a "pollution haven" for developed countries through international trade. The study by Lin and Liu (2015) suggested that foreign trade played a vital role in improving energy and environmental efficiency through both technology spillover of imported products and learning by doing in export. Antweiler *et al.* (2001) found evidence that trade improved the environment through allocative effects between industries. Their findings indicated that trade significantly reduced SO_2 emissions in the sample countries. According to recent theoretical studies, trade could affect pollution through not only inter-industry allocative effects but also resource allocation effects among heterogeneous enterprises, of which the latter may be more critical (Cherniwchan *et al.*, 2017).

Moreover, the "environmental Kuznets curve" (EKC) hypothesis argues that there is an inverted U-shaped relationship between environmental pollution that falls after rising with the increase in per capita income; that is, this branch of literature argues that the effect of trade on environmental pollution is nonlinear. Since trade is positively correlated with per capita income, it becomes one of the crucial factors in explaining the EKC. For developing countries, the scale effect of trade affecting the environment plays a major role in the initial stage of economic growth, during which environmental pollution increases. As the economy grows further, residents become more aware of environmental protection, and governments tighten environmental regulation. The technical and allocative effects of trade on the environment dominate gradually, and environmental pollution declines in this stage (Grossman and Krueger, 1995). Although the EKC has been extensively validated by macro data (Lin and Jiang, 2009), its cause and the timing of the inflection point are controversial. Lu (2012) explained this issue well, which will not be elaborated herein.

According to the above literature review, there have been extensive studies on the relationship between trade and environmental pollution. Nevertheless, there is still room for improvement in the following important aspects. Firstly, existing studies mainly use macro data to investigate the impact of trade on environmental pollution, whereas there are few studies using micro data. Secondly, existing literature mainly employed endogenous variables such as total volume of imports and exports and foreign direct investment (FDI) to measure trade barriers (or the extent of trade liberalization), which makes it difficult to attribute the empirical results to causality. Thirdly, existing literature did not distinguish between neutral and biased technical changes in examining the technical effects of trade affecting environmental pollution. However, according to the study by Lyubich *et al.* (2018), the difference in environmental efficiency among firms is much higher than that in total factor productivity (TFP); that is, neutral technical change can hardly explain the technical effects of trade on environmental pollution fully, and the effect of biased technical change should be examined.

In the light of the facts above, this paper contributes to the existing literature in the following aspects. Firstly, this paper processes China's Firm-Level Pollution Database and merges this unique and micro-level database with China's Industrial Enterprise Database and industry tariff rates reflecting the extent of trade liberalization, providing micro evidence of trade affecting environmental pollution in China. Secondly, the paper uses China's accession to the WTO as a quasi-natural experiment to effectively alleviate the endogeneity problem prevalent in the literature studying the relationship between trade and environmental pollution. Thirdly, although the quasi-natural experiment of China's accession to the WTO has been widely used in the existing literature (Yu, 2010; Jian *et al.*, 2014; Lu and Yu, 2015) to explore the impact of trade barrier reduction (trade liberalization), the study on the impact of trade on enterprises' pollution emissions based on it is scarce, and this paper serves as a useful supplement. Finally, the micro mechanisms of trade liberalization affecting enterprises' pollution behaviors are identified in this paper. Particularly, neutral and biased technical changes are further distinguished in this paper regarding the technical change mechanism of trade liberalization in affecting the pollution emission intensity of enterprises, which is new in the literature on how trade affects environmental pollution.

3. Data description and identification strategy

3.1 Data description

The research conducted in this paper mainly involves three datasets: China's Industrial Enterprise Database, China's Firm-Level Pollution Database and the World Integrated Trade Solution (WITS) database of the World Bank, among which China's Firm-Level Pollution Database is a unique data set that has not been widely used in academia. The research samples are limited to samples from 1998 to 2007, and require detailed elaboration. This approach is mainly based on the following considerations. Firstly, China experienced an extensive reduction in trade barriers during the period when it became a member of the WTO, and then China's import tariff rates declined sharply, which could be utilized in this paper as a rare quasi-natural experiment to identify the impact of trade on environmental pollution in China. Furthermore, this paper applies a difference in difference (DID) strategy to identify the effect of trade barrier reduction on enterprises' pollution emissions. In addition to the premise of parallel trends prior to policy implementation, another essential premise for identifying causal effect through the DID strategy is that there are no other policies that have systematic and heterogeneous effects on the outcome variables in the treatment and control groups after the implementation of the policy to be evaluated. Hence, the period of research samples after the implementation of the policy may not span too long. As the available enterprise-level data in China date back to 1998, extending the research samples to 2013 implies a post-WTO sample span of 13 years, whereas the pre-WTO sample span is only three years, which will affect the causal effect identification in this paper. Also, there are considerations about data availability and quality. Specifically, the paper's key variable, the enterprises' pollution emissions, comes from China's Firm-Level Pollution Database, of which only samples from 1998 to 2009 are available currently. Meanwhile, given China's accession to the WTO in 2001 and the relatively poor data quality about industrial enterprises during 2008–2009, this paper limits the sample period to 1998–2007. What is more, limiting the sample period to 2007 or earlier is also a common practice in recently published high-quality papers utilizing WTO as an exogenous policy shock (Lu and Yu, 2015; Brandt *et al.*, 2017).

As the core issue investigated in this paper is the impact of trade on enterprises' environmental pollution, the explained variable and the core explanatory variable in the econometric regression model were the pollution emission of enterprises and the degree of trade openness, respectively. Specifically, this paper adopted the emission intensity of SO_2, a main pollutant emitted by enterprises, as the explained variable, and the decline in industry import tariff rates as an indicator to measure the core explanatory variable – trade liberalization. Data about enterprises' pollution emissions were derived from China's Firm-Level Pollution Database, the indicator of trade liberalization was constructed based on tariff rates reported in the WITS Database of the World Bank and the other control variables came from China's Industrial Enterprise Database. It is necessary to merge China's Firm-Level Pollution Database and China's Industrial Enterprise Database with tariff rate data in the WITS Database to validate this study. Both China's Industrial Enterprise Database and China's Firm-Level Pollution Database have reported enterprise identification information such as the code, name, location, telephone number and postal code of companies based on a uniform standard, making it possible to merge the two databases. The specific method is as follows. Firstly, process China's Industrial Enterprise Database referring to the method of Brandt *et al.* (2012) and form industrial enterprise panel data. Secondly, construct pollution panel data using a similar approach. Subsequently, merge the industrial enterprise panel data with the pollution panel data based on the unique identifier created by the enterprise identification information and form the pollution–industrial enterprise panel data. Finally, as tariff rates in the WITS Database are at the product level, categorize the tariff rates into the industry level (three-digit) referring to the method of Brandt *et al.* (2017), and merge the tariff data into the pollution–industrial enterprise panel data according to the adjusted three-digit industry codes to form the final panel data that meet the requirements of empirical research in this paper.

High-quality data are the prerequisite and basis for carrying out empirical analysis. China's Industrial Enterprise Database and WITS Database have been extensively used in existing studies, and their quality is not an issue. Compared with these two databases, China's Firm-Level Pollution Database may have data reliability problems, because pollution emissions in China's Firm-Level Pollution Database are self-reported by enterprises that often have the motive to underreport their pollution emissions. To alleviate this concern, this paper examines the relationship between enterprises' SO_2 emissions and other variables. The logic behind this approach is that if enterprises underreport or even arbitrarily report SO_2 emissions, the SO_2 data may not be systematically correlated with those variables that are supposed to be correlated. Figure 1 indicates the correlation between enterprises' SO_2 emissions and other variables, in which subfigures 1 and 2 show that enterprises' SO_2 emissions are increased with waste gas and soot emissions, which is highly consistent with intuitive understanding. One possible concern for it is that enterprises may underreport SO_2, waste gas and soot emissions at the same time to avert the government's environmental regulation. Subfigure 3 further demonstrates the relationship between SO_2 emissions and coal consumption, which leads to another intuitive conclusion – enterprises' SO_2 emissions increase with coal consumption. A common concern about the above three subfigures is that the waste gas emissions, soot emissions and coal consumption are all derived from China's Firm-Level Pollution Database. Subfigure 4 shows the relationship between enterprises' SO_2 emissions and their scale reported in China's Industrial Enterprise Database, which also leads to a reasonable conclusion.

3.2 Identification strategy

To effectively alleviate the endogeneity problem, the author constructed the following DID model to identify the impact of trade barrier reduction (i.e. trade liberalization) on the emission intensity of enterprises' main pollutant SO_2 in China.

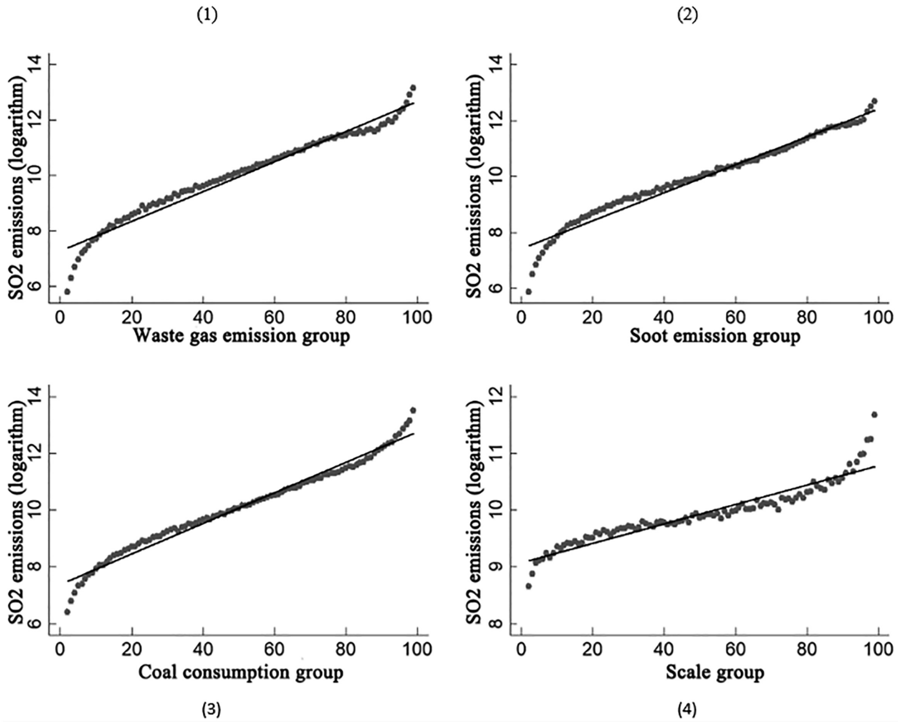


Figure 1.
Relationship between enterprises' SO_2 emissions and related variables

Note(s): The figure was plotted by sorting the emissions of waste gas and soot, coal consumption, and scale in ascending order, dividing them into 100 equal parts, and calculating the mean of SO2 emissions in each group, with the group number as the horizontal coordinate and the mean of SO2 emissions in each group as the vertical coordinate

$$\ln SI_{ijkt} = \alpha \cdot \Delta Tariff_{2001,j} \times Post_{2001} + X'\beta + \gamma_i + \eta_j + \lambda_{kt} + \varepsilon_{ijkt} \tag{1}$$

where i represents the enterprise, j represents the 3-digit industry, k represents the 2-digit industry and t represents the year. The explained variable $\ln SI_{ijkt}$ indicates the logarithm of SO_2 emission intensity of enterprise i in the year t, which is obtained by dividing SO_2 emission by the enterprises' gross output value in China's Industrial Enterprise Database. $\Delta Tariff_{2001,j}$ indicates the decline of import tariff rates from 2001 to 2002 in the three-digit industries; the larger the value, the larger the extent of trade liberalization. $Post_{2001}$ indicates the dummy variable for the year of China's accession to the WTO. If the year is after or is 2001, $Post_{2001} = 1$; otherwise, $Post_{2001} = 0$. $\Delta Tariff_{2001,j} \times Post_{2001}$ is the core explanatory variable of the econometric regression model, and α is an coefficient of interest in this paper, which measures the percentage change in enterprises' SO_2 emission intensity for every unit increase in trade liberalization. X is the control variable, γ_i is the enterprise fixed effect (FE), η_j is the three-digit industry FE, λ_{kt} is the cross-product term of two-digit industry and year dummy variable and ε_{ijkt} is the error term.

4. Empirical results

This section mainly reports the DID results of trade liberalization affecting enterprises' SO_2 emission intensity, tests the validity of the premises of econometric identification strategy and conducts a series of robustness analyses.

4.1 Empirical results

In examining the causal relationships among variables based on the econometric regression model, regression coefficient (RC) and its standard error (SE) are often affected by fixed effects (FEs) and the standard error (SE) clustering level. To ensure the reliability of research conclusions, the author first examined the impact of different FEs and the SE clustering level on the findings without adding any other control variables before reporting the baseline empirical results of this paper. The corresponding regression results are presented in Table 1. Columns 1–4 examine the effects of FEs under different control variables on the regression results; columns 5–8 examine the effects of SEs clustered at different levels on the regression results. It can be observed that the conclusion that trade liberalization significantly reduces enterprises' SO_2 emission intensity is highly robust. Considering the credibility of research results, all regression models should have the same FE and clustering level as in column 8; that is, FE under the strictest control and SE clustered at the strictest level (three-digit industries).

To identify the causal effect of trade liberalization on enterprises' SO_2 emission intensity effectively, the author added three types of variables to the regression equation in sequence: predetermined variables affecting the decline of import tariff rates, other policy variables during the same period of China's accession to the WTO and enterprise control variables. The regression results are presented in Table 2. Firstly, the identification parameter α requires that the decline of tariff rates should not be correlated with industry characteristics. However, in determining the extent of tariff rate decline for a given industry, the government may consider the export intensity, the proportion of the state-owned economy, the proportion of employment, industrial concentration in that industry and so forth. These variables that influence policymaking are often referred to as predetermined variables. Therefore, to control for these factors, this paper includes in the regression the cross-product term of the values of these variables taken in the year before the policy was implemented and the dummy variable for the year of China's accession to the WTO ($Post_{2001}$). The export intensity is expressed as the ratio of export sales to the industrial added value; the proportion of the state-owned economy is expressed as the ratio of the value-added of the state-owned economy to the total value-added of this industry; the proportion of employment is expressed as the ratio of employment in this industry to the total employment in the country; and the industrial concentration is expressed as the Herfindahl-Hirschman index (HHI).

Column 1 shows the regression results without adding any control variables, and column 2 further controls the cross-product term of predetermined variables and the dummy variable for the year of China's accession to the WTO. After controlling for predetermined variables, there is no significant change in the effect of trade liberalization on the reduction of enterprises' SO_2 emission intensity. Secondly, during the same period of China's accession to the WTO, China also implemented other policies, especially the policies of restructuring state-owned enterprises and encouraging foreign investment. Hence, the effect of trade liberalization on enterprises' SO_2 emission intensity is likely to have included the effects of both policies. Thus, the author further added the proportions of state-owned and foreign-owned economies to the regression equation to control for the effects of these two policies. The corresponding regression results are presented in column 3. The conclusion that trade liberalization significantly reduces enterprises' SO_2 emission intensity still holds. Finally, all the above control variables are at the three-digit industry level. To eliminate the effect of

Table 1. Effect of trade liberalization on enterprises' SO_2 emission intensity (preliminary regression results)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ln*SI*	ln*SI*	ln*SI*	ln*SI*	ln*SI*	ln*SI*	ln*SI*	ln*SI*
	Fixed effects under different control variables				Standard errors clustered at different levels			
$\Delta Tariff_{2001} \times Post_{2001}$	-0.0220^{***}	-0.0226^{***}	-0.0213^{***}	-0.0279^{***}	-0.0279^{***}	-0.0279^{***}	-0.0279^{***}	-0.0279^{***}
	(0.0019)	(0.0020)	(0.0024)	(0.0033)	(0.0047)	(0.0051)	(0.0056)	(0.0057)
Enterprise FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Three-digit industry FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Two-digit industry FE × time trend	No	No	Yes	No	No	No	No	No
Two-digit industry × year FE	No	No	No	Yes	Yes	Yes	Yes	Yes
Clustered at the enterprise level	No	No	No	No	Yes	No	No	No
Clustered at three-digit industry × year level	No	No	No	No	No	Yes	No	No
Clustered at three-digit industry × year and enterprise level	No	No	No	No	No	No	Yes	No
Clustered at the three-digit industry level	No	No	No	No	No	No	No	Yes
Sample size	196,604	196,604	196,604	196,604	196,604	196,604	196,604	196,604
Adjusted R^2	0.759	0.759	0.760	0.761	0.761	0.761	0.761	0.761

Note(s): *, ** and *** indicate statistically significant at 10%, 5% and 1% significance levels, respectively; the same in the tables below enterprise-level factors, column 4 controls total factor productivity (TFP), log capital-labor ratio, log age and its squared term of enterprises. Column 4 indicates that enterprises' SO_2 emission intensity decreases by 2.16% for every unit increase in trade liberalization.

4.2 Premise testing

Although the DID estimates in Tables 1 and 2 robustly indicate that trade liberalization significantly reduces enterprises' SO_2 emission intensity in China, the endogeneity problems caused by omitted variables, measurement errors, enterprise self-selection and other factors cannot be completely ruled out. Considering the reliability of the research results, it is necessary to test the premise of the DID identification strategy.

(1) Parallel Trend Premise Test

The core premise for the validity of the DID model is the parallel trend. Regarding the settings in this study, the parallel trend premise implies that if China had not joined the WTO, the trends of enterprises' SO_2 emission intensity in various groups of different degrees of trade liberalization should be generally parallel. This premise is tested by the event analysis framework in this paper. The following econometric regression equation is formally set.

$$\ln SI_{ijkt} = \sum_{\tau=1999}^{2007} \alpha_\tau \cdot \Delta Tariff_{2001,j} \times D_\tau + X'\beta + \gamma_i + \eta_j + \lambda_{kt} + \varepsilon_{ijkt} \quad (2)$$

where D_τ is the year dummy variable, α_τ is the key parameter of concern and the other letters have the same meaning as in Eqn. (1). It can be observed that in the model of Eqn. (2), the initial year of the sample (1998) is set as the base year for the event analysis. Hence, the specific meaning of the parameter α_τ is whether there is a significant difference in enterprises' SO_2 emission intensity in different groups of trade liberalization in the year τ compared with that in 1998. The parallel trend premise holds if α_τ is not significantly different from 0 before China's accession to the WTO. The estimates of parameter α_τ and 95% confidence intervals are plotted in Figure 2, which indicates that the DID model set in this paper has passed the parallel trend test.

(2) Placebo Test

In examining the effect of trade liberalization on enterprises' pollution emissions, the above DID model controls rich fixed effects and main factors that may lead to non-random core explanatory variables and has passed the parallel trend test. Nevertheless, the interference of omitted variables cannot be wholly eliminated theoretically. For this reason, the author

	(1) $\ln SI$	(2) $\ln SI$	(3) $\ln SI$	(4) $\ln SI$
$\Delta Tariff_{2001} \times Post_{2001}$	−0.0279***	−0.0250***	−0.0234***	−0.0216***
	(0.0057)	(0.0060)	(0.0063)	(0.0070)
Predetermined variables × $Post_{2001}$	No	Yes	Yes	Yes
Other policy variables	No	No	Yes	Yes
Enterprise control variables	No	No	No	Yes
Sample size	196,604	196,604	196,604	184,412
Adjusted R^2	0.761	0.761	0.761	0.772

Note(s): All regressions require simultaneous control for enterprise FE, year FE, three-digit industry FE, two-digit industry × year FE and SE clustered at the three-digit industry level; the same in the tables below

Table 2. Effect of trade liberalization on enterprises' SO_2 emission intensity (baseline regression results)

conducted a placebo test for the baseline regression results presented in column 4 of Table 2. Specifically, the author randomly selected the year of China's WTO accession and generated data on the decline in industry tariff rates, and repeated this process 500 times to generate 500 sets of random samples; then, he regressed each random sample separately to obtain 500 estimated coefficients of the impact of trade liberalization on the SO_2 emission intensity of enterprises. Figure 3 shows the cumulative probability density function of regression coefficients, where only four coefficients are smaller than the parameter estimates derived from the baseline regression results.

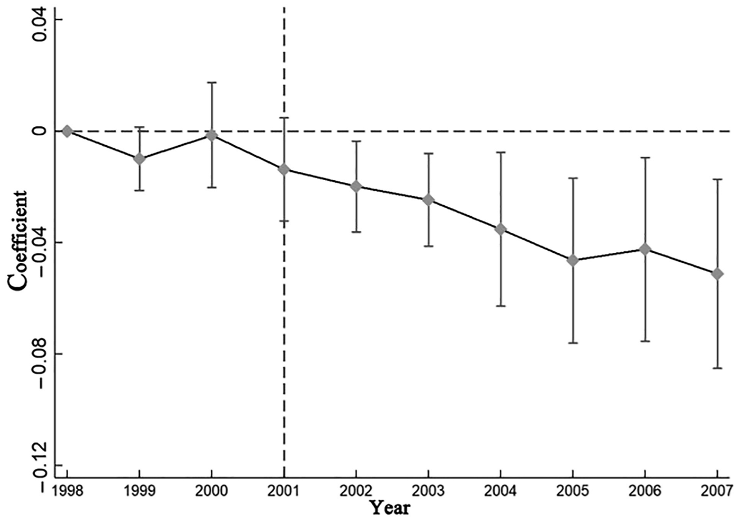


Figure 2.
Parallel trend premise test

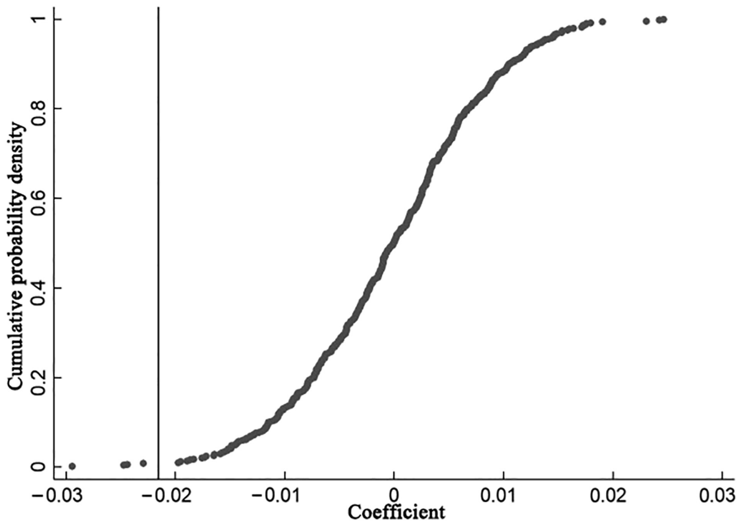


Figure 3.
Placebo test

(3) Other Tests

To further ensure the reliability of the research results, the author also performed a series of identification tests other than the parallel trend and placebo tests on the aforesaid DID model. Firstly, the influence of expected effects on the regression results was investigated. China had been negotiating for 15 years before its formal accession to the WTO. As a result, enterprises might have expectations about China's accession to the WTO and adjust their production and business behaviors accordingly, thus leading to biased estimation results. To control for the effect of enterprises' expectations on the research results, the author added a cross-product term of $\Delta Tariff_{2001}$ and the dummy variable for the year before China's formal accession to the WTO to the regression equation. The corresponding regression results are presented in columns 1 and 2 of Table 3, which indicates that the RC of the trade liberalization variable basically remains unchanged after the expectations term is added, and the coefficient of the expectations term is not significant.

Furthermore, the use of instrumental variable regressions was also considered in this paper. The tariff rate in 1997, the year before the initial year of research samples, was chosen as the instrumental variable of $\Delta Tariff_{2001}$. On the one hand, the historical tariff rate is an established variable on which the factors affecting enterprises' SO_2 emission intensity in the current period have no impact. Thus, it complies with the exogeneity premise of an effective instrumental variable. On the other hand, historical tariff rates are highly correlated with trade liberalization indicator $\Delta Tariff_{2001}$; that is, the industry with a higher tariff rate in 1997 had a greater decline of tariff rates between 2001 and 2002 (as shown in Figure 4). Thus, it complies with the correlation premise of an effective instrumental variable. The results of instrumental variable regressions are presented in columns 3 and 4 of Table 3, indicating that the conclusion that trade liberalization reduces enterprises' SO_2 emission intensity in China still holds.

4.3 Robustness analysis

(1) Replacement of trade liberalization indicators

As stated above, the quasi-natural experiment of China's accession to the WTO led to varying degrees of reduction in import tariff rates of various industries during 2001–2002. Accordingly, the decline of tariff rates during 2001–2002 ($\Delta Tariff_{2001}$) is taken as a proxy variable for the extent of trade liberalization in the baseline model of this paper. Industries with a greater decline of tariff rates are more significantly affected by trade liberalization, and

	(1) ln*SI*	(2) ln*SI*	(3) ln*SI*	(4) ln*SI*
	Expected effects		Instrumental variable regression	
$\Delta Tariff_{2001} \times Post_{2001}$	−0.0269***	−0.0195**	−0.0306***	−0.0220***
	(0.0072)	(0.0079)	(0.0055)	(0.0059)
$\Delta Tariff_{2001} \times Dum_{2000}$	0.0022	0.0047		
	(0.0088)	(0.0107)		
Predetermined variables × $Post_{2001}$	No	Yes	No	Yes
Other policy variables	No	Yes	No	Yes
Enterprise control variables	No	Yes	No	Yes
Sample size	196,604	184,412	196,604	184,412
Adjusted R^2	0.776	0.772	–	–

Table 3. Further identification tests

vice versa. Besides, the tariff rate in 2001 was also widely used as a proxy variable for trade liberalization in the existing literature. The logic is that the industry with a higher tariff rate in 2001 ($Tariff_{2001}$) has a greater decline of tariff rates after China's accession to the WTO (Figure 5), and thus is more significantly affected by trade liberalization (Lu and Yu, 2015). Based on this understanding, the author replaced $\Delta Tariff_{2001}$ in the baseline regression model with $Tariff_{2001}$ for the robustness tests, and the results are presented in Table 4. Although the absolute values of main RCs decrease, they are all significantly negative.

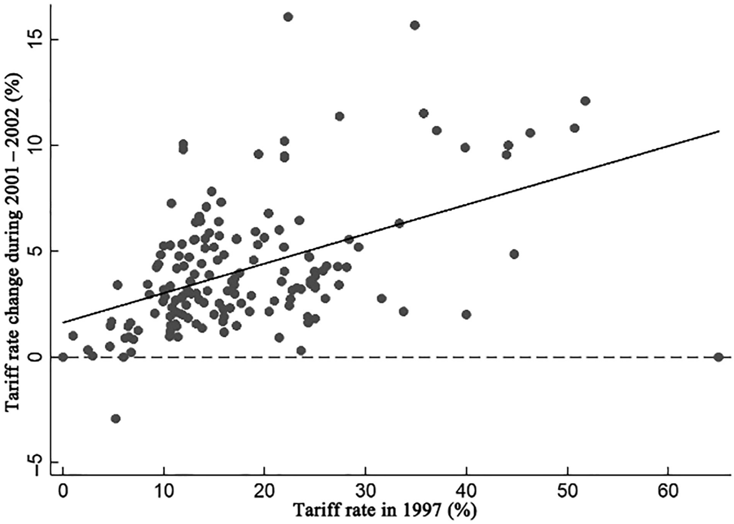


Figure 4.
Correlation of instrumental variables

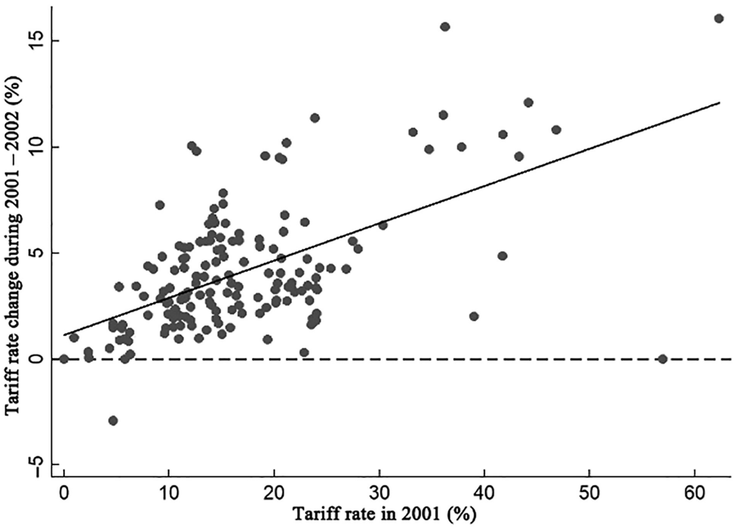


Figure 5.
Tariff rate in 2001 and tariff rate change during 2001–2002

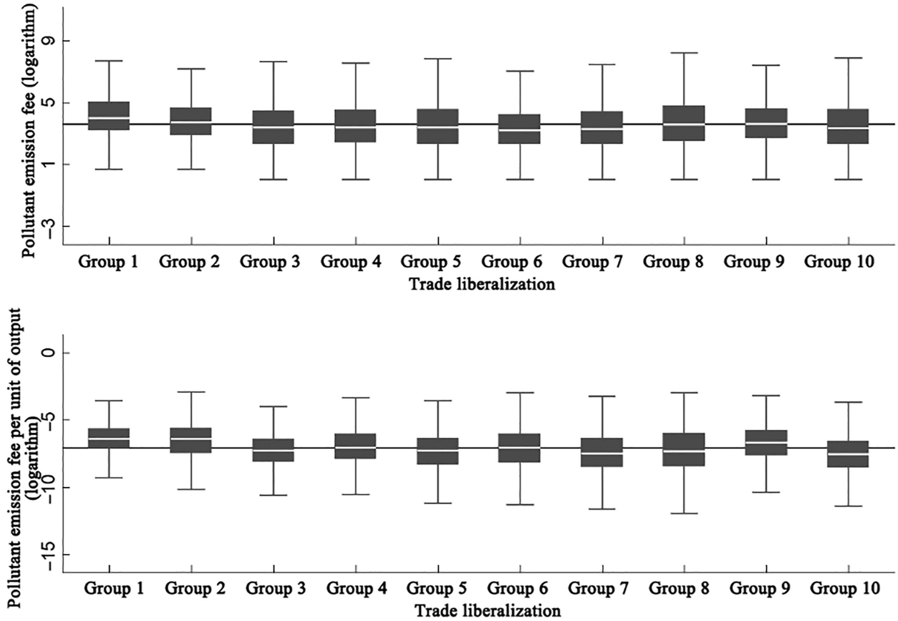
(2) Consideration of environmental regulation

Another concern regarding the aforesaid conclusion is that the effect of trade liberalization on the reduction in enterprises' SO_2 emission intensity in China may include the influence of environmental regulations. On the one hand, existing studies suggest that environmental regulations can significantly affect pollution emissions (Wang *et al.*, 2008; Greenstone and Hanna, 2014; Tu and Shen, 2015; Shapiro and Walker, 2018). On the other hand, the extent of trade liberalization is closely related to environmental regulations (Grossman and Krueger, 1995; Zhu *et al.*, 2011). In fact, China has implemented extensive environmental regulation policies in the research period of this paper, such as the Scheme of Acid Rain and Sulfur Dioxide Pollution Control Zones (the Scheme of Two Control Zones), which was adopted and implemented in 1998, and the policy regarding total emission control of two pollutants, chemical oxygen demand (COD) and sulfur dioxide (SO_2), in the "Eleventh Five-Year" Plan (the Pollution Control Policy in the Eleventh Five-Year Plan). Enterprises' pollutant emission fees in 2004 were reported in China's Industrial Enterprise Database. Before the potential impact of environmental regulations on the regression results is formally investigated, the characteristics of enterprises' pollutant emission fees are preliminarily analyzed. In general, the pollutant emission fee can reflect the intensity of environmental regulations to some extent. If there are no systematic differences in the pollutant emission fee of enterprises in different trade liberalization groups, the omission of environmental regulation factors in the regression equation is unlikely to have a significant impact on the estimation results. To examine this point, the author plotted the boxplot for pollutant emission fees of enterprises in different trade liberalization groups, as shown in Figure 6. It can be observed that there are no significant systematic differences in the pollutant emission fee of enterprises in different trade liberalization groups, which implies that environmental regulatory factors may not cause excessive interference in the baseline regression results.

However, levying pollutant emission fee is only one aspect of environmental regulations and can hardly reflect the whole picture. How to select the appropriate indicators to measure the government's environmental regulations is a major challenge in the existing literature (Chen and Chen, 2018). As the regression analysis above used enterprise-level micro data, the influence of FEs on the conclusion can be eliminated by controlling for FEs of a series of environmental regulatory policies at the implementation level. Most environmental regulatory policies in China are implemented on an administrative region basis. The Scheme of Two Control Zones is implemented on a prefecture-level city basis, while the implementation of the Pollution Control Policy in the Eleventh Five-Year Plan was on a provincial basis. These environmental regulation factors can be controlled by adding the cross-product term of administrative unit FE and year FE to the regression equation. The corresponding results are presented in columns 1 and 2 of Table 5. It is not difficult to see that the estimation coefficients are still significantly negative and consistent with the baseline regression estimates. Moreover, environmental regulation can vary across industries in the

	(1) $\ln SI$	(2) $\ln SI$	(3) $\ln SI$	(4) $\ln SI$
$Tariff_{2001} \times Post_{2001}$	-0.0104^{***}	-0.0088^{***}	-0.0083^{***}	-0.0076^{**}
	(0.0021)	(0.0023)	(0.0022)	(0.0029)
Predetermined variables $\times$ $Post_{2001}$	No	Yes	Yes	Yes
Other policy variables	No	No	Yes	Yes
Enterprise control variables	No	No	No	Yes
Sample size	196,808	196,808	196,808	184,607
Adjusted R^2	0.761	0.761	0.761	0.772

Table 4.
Replacement of trade liberalization indicators



Note(s): In the figure, the extent of trade liberalization is divided into 10 groups in ascending order, with the horizontal line indicating the mean

Figure 6. Boxplot for pollutant emission fees of enterprises in different trade liberalization groups

same region. To eliminate the effect of this factor, the author added the cross-product terms of administrative unit and industry FE to the regression model based on the regression model in columns 1 and 2 of Table 5 (as shown in columns 3 and 4 of Table 5), respectively. The regression results remain robust.

(3) Robustness Analysis: SO_2 Emission Intensity under Different Output Indicators

It should be noted that in the above empirical analysis, the output indicator used to calculate the SO_2 emission intensity (the explained variable) is the gross industrial output value of enterprises reported in China's Industrial Enterprise Database. A related concern is a possible

	(1) ln*SI*	(2) ln*SI*	(3) ln*SI*	(4) ln*SI*
$\Delta Tariff_{2001} \times Post_{2001}$	−0.0250***	−0.0251***	−0.0231***	−0.0235***
	(0.0086)	(0.0086)	(0.0072)	(0.0077)
Province × year FE	Yes	No	Yes	No
City × year FE	No	Yes	No	Yes
Province × two-digit industry FE	No	No	Yes	No
City × two-digit industry FE	No	No	No	Yes
Predetermined variables × $Post_{2001}$	Yes	Yes	Yes	Yes
Other policy variables	Yes	Yes	Yes	Yes
Enterprise control variables	Yes	Yes	Yes	Yes
Sample size	184,411	184,411	184,379	184,227
Adjusted R^2	0.776	0.777	0.786	0.787

Table 5. Consideration of environmental regulations

discrepancy between the gross industrial output value of enterprises reported in China's Industrial Enterprise Database and Firm-Level Pollution Database, which may lead to a change in the main conclusions stated above. In fact, the data comparison reveals that the gross industrial output values in the two databases are not exactly the same. To alleviate this concern, the author adopted the gross industrial output value from China's Firm-Level Pollution Database to calculate the SO_2 emission intensity, and the corresponding regression results are presented in columns 1 and 2 of Table 6. The results indicate that rather than changing the core conclusion in the baseline regression, it has even enhanced the conclusion of the baseline regression results that trade liberalization itself significantly reduces enterprises' SO_2 emission intensity in China. Moreover, in addition to the gross industrial output value, the industrial added value is also a crucial indicator for enterprise output. Hence, the industrial added value was also used to represent enterprise output in this paper. The regression results in columns 3 and 4 of Table 6 indicate that using industrial added value as an output indicator to calculate enterprises' SO_2 emission intensity does not affect the conclusions of the baseline regression either.

(4) Enterprise Entry/Exit and Industry Transfer

Relevant studies have indicated that market entry and exit of enterprises is a common phenomenon. If there are significant differences in the pollution emission intensity of incumbent, entering and exiting enterprises, the market entry and exit of enterprises may lead to sample selection problems. Hence, when examining the influence of trade liberalization policies on enterprises' pollution emission intensity, it is necessary to further explore the potential effect of market entry and exit of enterprises on the baseline regression results [1]. The results reported in Table 7 indicate that the basic conclusion that trade liberalization policies significantly reduce SO_2 emission intensity remains unchanged, whether using samples excluding the entering enterprises or the exiting enterprises or excluding both entering and exiting enterprises (i.e. balanced panel data). Moreover, the regression coefficient (RC) value of the core explanatory variable shows no significant changes compared to the baseline situation.

In the regression model of this paper, the core explanatory variable trade liberalization is at the three-digit industry level, and the explained variable SO_2 emission intensity is at the firm level. Thus, influenced by trade liberalization policies, enterprises may transfer across industries. If there are systematic differences in SO_2 emission intensity between these enterprises with transfer and those without transfer across industries, the self-selection behaviors of enterprises regarding transferring across industries are likely to affect previous basic conclusions significantly. Hence, it is necessary to explore the effect of the cross-industry transfer of enterprises. Firstly, the author calculated the number of

	(1) lnSI	(2) lnSI	(3) lnSI	(4) lnSI
	Total industrial output value (from China's firm-level pollution database)		Industrial added value	
$\Delta Tariff_{2001} \times Post_{2001}$	-0.0292^{***}	-0.0248^{***}	-0.0323^{***}	-0.0292^{***}
	(0.0066)	(0.0079)	(0.0067)	(0.0075)
Predetermined variables × $Post_{2001}$	No	Yes	No	Yes
Other policy variables	No	Yes	No	Yes
Enterprise control variables	No	Yes	No	Yes
Sample size	195,024	182,284	149,398	143,001
Adjusted R^2	0.734	0.737	0.723	0.785

Table 6. SO_2 emission intensity under different output indicators

Table 7.
Effect of market entry and exit of enterprises on the baseline regression results

	(1)	(2)	(3)	(4)	(5)	(6)
	Exclude the entering enterprises		Exclude the existing enterprises		Exclude both the entering and exiting enterprises	
	ln*SI*	ln*SI*	ln*SI*	ln*SI*	ln*SI*	ln*SI*
$\Delta Tariff_{2001} \times Post_{2001}$	−0.0302***	−0.0259***	−0.0286***	−0.0224***	−0.0265***	−0.0171**
	(0.0068)	(0.0087)	(0.0054)	(0.0067)	(0.0069)	(0.0084)
Predetermined variables × $Post_{2001}$	No	Yes	No	Yes	No	Yes
Other policy variables	No	Yes	No	Yes	No	Yes
Enterprise control variables	No	Yes	No	Yes	No	Yes
Sample size	158,385	150,051	183,194	172,477	18,770	18,012
Adjusted R^2	0.771	0.781	0.763	0.773	0.749	0.770

enterprises transferring across three-digit industries. The results indicate that in the sample period of this paper, only 878 enterprises transferred across industries every two years, accounting for 3.36% and 3.12% of the sample enterprises in the first and last years of the period, respectively. This suggests that cross-industry transfers of enterprises should not change the basic conclusions stated above. Moreover, the concern that cross-industry transfers may interfere with the basic conclusions of the baseline regression analysis is further alleviated from the following two perspectives. Firstly, the research samples are limited to a period of two years before and after the implementation of the policies. The logic of this approach is that due to the sunk cost of investment and the prevalence of economic cycles, it often takes enterprises some time to transfer across industries, especially for those large-scale heavy chemical enterprises and heavy-polluting enterprises. Secondly, trade liberalization indicators are constructed based on two-digit industry tariff rates in the same manner as the baseline regression analysis. The results indicate that the signs of the estimated RC value of the core explanatory variable are consistent with the baseline regression results, and all of them have passed the significance test with a significance level of 5% [2].

(5) Robustness Analysis: Others

To further enhance the reliability of the research results, in addition to replacing the trade liberalization measurement indicator and considering the effect of environmental regulations, a series of other robustness analyses were performed on the baseline regression results in this paper. Firstly, one concern regarding the setting of the above DID model is that although China formally joined the WTO in 2001, most of the relevant policies only began to be implemented in and after 2002 gradually. Hence, the year with the dummy variable value for the year of China's WTO accession taking 1 was set to 2002 and thereafter in this paper. Secondly, the cross-product term of the predetermined variable and the dummy variable for the year of China's WTO accession in the baseline regression was replaced with the cross-product term of the predetermined variable and the time-trend cubic polynomial. Thirdly, the author found that the sum data obtained based on China's Firm-Level Pollution Database after 2005 deviated from the officially reported data to some degree and thus deleted the data after 2005 for robustness analysis. Finally, to mitigate the impact of endogeneity of control variables on the research results, the author also examined the case where all control variables were lagged by one period. None of the above robustness analyses impacted the conclusions of the baseline regression results.

5. Mechanism analysis

The above content has answered the question of whether trade liberalization affects enterprises' pollution in China through abundant identification tests and a series of robustness analyses. This section builds on it to examine the specific transmission mechanism by which trade liberalization affects enterprises' pollution in China, that is, to answer how trade liberalization affects enterprises' pollution in China.

5.1 Adjustment of output and pollution

The results of the above empirical analysis indicate that trade liberalization significantly reduces enterprises' SO_2 emission intensity in China. As enterprises' SO_2 emission intensity is equal to their SO_2 emission divided by their output, the changes in their SO_2 emission intensity may be caused by changes in SO_2 emission, or their output or both SO_2 emission and output simultaneously. To investigate this mechanism, the logarithms of SO_2 emissions ($\ln SO_2$) and enterprise output ($\ln Output$) were used as explained variables in this paper to perform regression on the trade liberalization index. The regression results are presented in Table 8. It can be clearly observed that in the regression with enterprises' SO_2 emissions as the explained variable (columns 1 and 2), the trade liberalization coefficient estimate has passed the significance test at the 1% level and is numerically very close to the baseline case where SO_2 emission intensity was used as the explained variable. In the regression with enterprises' output as the explained variable (columns 3 and 4), the trade liberalization coefficient estimate is not significant. Hence, trade liberalization mainly reduces enterprises' SO_2 emission intensity in China by decreasing their SO_2 emissions rather than by increasing their output. It should be noted that the RC of output on trade liberalization is not significant, which is not inconsistent with the findings of existing theoretical literature that trade liberalization is likely to increase enterprise size. The reason is that the regression analysis in this paper controls for a range of enterprises characteristics as well as numerous FEs. Trade liberalization may affect enterprise size through control variables and FEs of enterprise characteristics. For example, the classical trade theory literature indicates that trade liberalization can reduce the fixed cost per unit of product produced by enterprises, thereby affecting enterprise size, while fixed costs are often absorbed into the FEs in the regression analysis.

5.2 Generation and treatment of pollution

According to Table 8, trade liberalization reduces enterprises' SO_2 emission intensity mainly by decreasing the enterprises' SO_2 emissions. Are enterprises' SO_2 emissions reduced due to the decrease of SO_2 generated during the production or the increase of SO_2 treated in the end-of-pipe treatment? This influence mechanism of trade on pollution has not been thoroughly examined due to the limitation of the availability of micro data about pollution of companies. As China's Firm-Level Pollution Database used in this paper contains volumes

	(1) $\ln SO_2$	(2) $\ln SO_2$	(3) $\ln Output$	(4) $\ln Output$
$\Delta Tariff_{2001} \times Post_{2001}$	-0.0312^{***}	-0.0233^{***}	-0.0033	-0.0017
	(0.0066)	(0.0070)	(0.0041)	(0.0030)
Predetermined variables $\times$ $Post_{2001}$	No	Yes	No	Yes
Other policy variables	No	Yes	No	Yes
Enterprise control variables	No	Yes	No	Yes
Sample size	197,605	184,591	196,916	184,706
Adjusted R^2	0.755	0.758	0.879	0.934

Table 8. Effect of trade liberalization on enterprises' SO_2 emissions and output

of SO_2 generation and removal, it is possible to explore whether the reduction in enterprises' SO_2 emissions is caused by the production or the treatment side. In this paper, the logarithms of SO_2 generation amount (ln$SO_2_Produce$) and SO_2 removal amount (lnSO_2_Remove) were used as explained variables to perform regression on trade liberalization, and the regression results are presented in Table 9. It can be seen from the table that trade liberalization significantly reduces enterprises' SO_2 production. Although the regression results in column 3 indicate that trade liberalization significantly reduces enterprises' SO_2 removal amount, the effect of trade liberalization on enterprises' SO_2 removal is no longer significant after control variables were added. This suggests that trade liberalization reduces SO_2 emissions by decreasing the volume of SO_2 produced by enterprises rather than increasing the volume of SO_2 removed by them.

5.3 Coal utilization

According to the baseline regression model, trade liberalization significantly reduces enterprises' SO_2 emission intensity in China. Essentially, the problem of pollution emissions is about energy use, and most SO_2 emissions are caused by coal consumption. On this basis, it can be inferred that if trade liberalization does significantly reduce SO_2 emission intensity, reducing coal use intensity is a crucial influencing channel. In fact, coal consumption accounts for up to 60% of primary energy consumption in China, a country whose resource endowment is dominated by coal. Trade liberalization is conducive to diversifying the types of energy used in China and optimizing the energy structure, thus alleviating the problem of an excessively high proportion of coal use. Hence, under the condition that trade liberalization does not significantly change the output of enterprises, trade liberalization can reduce enterprises' SO_2 emission intensity by decreasing the intensity of coal use. To verify this mechanism, the author replaced the explained variable (enterprises' SO_2 emission intensity) by coal use intensity (lnCI). In regards to the robustness of results, the stepwise regression results are presented in Table 10 (similar to Table 2); that is, new control variables were added

Table 9. Generation and treatment of pollution

	(1) ln$SO_2_Produce$	(2) ln$SO_2_Produce$	(3) lnSO_2_Remove	(4) lnSO_2_Remove
$\Delta Tariff_{2001} \times Post_{2001}$	-0.0294^{***}	-0.0217^{***}	-0.0185^{**}	-0.0088
	(0.0070)	(0.0080)	(0.0078)	(0.0088)
Predetermined variables × $Post_{2001}$	No	Yes	No	Yes
Other policy variables	No	Yes	No	Yes
Enterprise control variables	No	Yes	No	Yes
Sample size	197,605	184,591	51,165	47,784
Adjusted R^2	0.776	0.779	0.780	0.781

Table 10. Effect of trade liberalization on enterprises' coal use intensity

	(1) lnCI	(2) lnCI	(3) lnCI	(4) lnCI
$\Delta Tariff_{2001} \times Post_{2001}$	-0.0192^{***}	-0.0178^{***}	-0.0182^{***}	-0.0168^{***}
	(0.0055)	(0.0044)	(0.0046)	(0.0041)
Predetermined variables × $Post_{2001}$	No	Yes	Yes	Yes
Other policy variables	No	No	Yes	Yes
Enterprise control variables	No	No	No	Yes
Sample size	177,995	177,995	177,995	166,939
Adjusted R^2	0.871	0.871	0.871	0.885

sequentially from columns 1 to 4. Regardless of the control variables, trade liberalization significantly reduces the intensity of coal use in China. It is not difficult to see that the results in Table 10 have also proved the robustness of the research results of this paper.

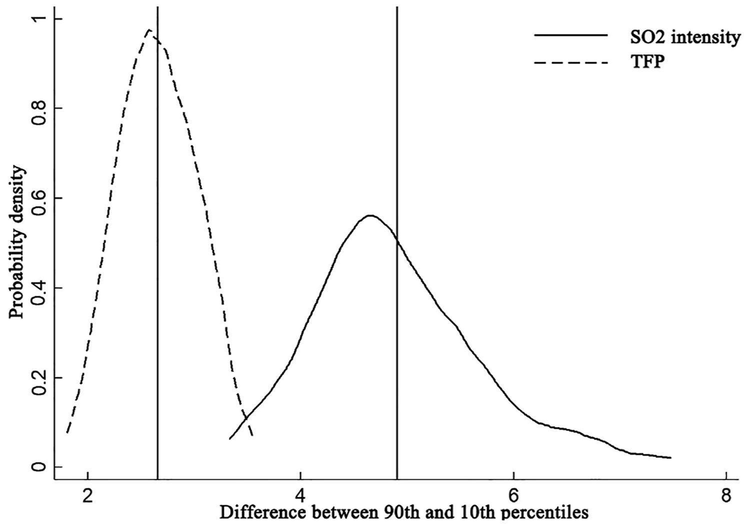
To further justify that trade liberalization may affect enterprises' SO_2 emission intensity through influencing the channel of enterprises' coal use intensity, regression was further performed on trade liberalization with the logarithms of waste gas emission intensity ($\ln WgasI$), wastewater emission intensity ($\ln WwaterI$) and COD emission intensity ($\ln COD$) as explained variables in this paper. The logic is that if coal use intensity is a crucial mechanism by which trade liberalization affects enterprises' SO_2 emission intensity, the intensity of waste gas emissions, which is closely related to coal use, should be affected by trade liberalization significantly, whereas the intensity of wastewater and COD emissions, which are not closely related to coal use, should be affected by trade liberalization less significantly. Table 11 indicates that trade liberalization significantly reduces the intensity of waste gas emissions, but its effect on the intensity of wastewater and COD emissions is not significant.

5.4 Technical change

Enterprises' SO_2 emission intensity is the volume of SO_2 emitted per unit of output and thus a concept of efficiency (reciprocal). From this perspective, enterprises' SO_2 emission intensity should be closely related to technical change. TFP has the same effect on various input factors and thus is a neutral technical change. However, since the study by Acemoglu (2002), more and more scholars have found the importance of distinguishing between neutral technical change (NTC) and biased technical change (BTC) when explaining economic phenomena. In addition, related studies have indicated that enterprise TFP differences cannot explain pollution intensity differences effectively. For example, Lyubich *et al.* (2018) found that the heterogeneity of enterprises' pollution emission intensity was far higher than that of TFP, similar to the findings of this paper. Figure 7 shows the distribution of SO_2 emission intensity (logarithm) differences among enterprises in three-digit industries and TFP differences in China. Specifically, the author calculated the differences between the 90th and 10th percentiles of SO_2 emission intensity of enterprises in the three-digit industries and plotted their distribution. The distribution of TFP differences among enterprises was plotted in the same way. The figure indicates that the heterogeneity of SO_2 emission intensity among enterprises is significantly higher than that of TFP, which suggests that NTC (TFP) may not explain the decline in enterprises' SO_2 emission intensity due to trade liberalization well, inspiring the author to distinguish between NTC and BTC in this paper in examining the mechanisms by which trade liberalization affects enterprises' SO_2 emission intensity in China.

	(1) $\ln WgasI$	(2) $\ln WgasI$	(3) $\ln WwaterI$	(4) $\ln WwaterI$	(5) $\ln COD$	(6) $\ln COD$
$\Delta Tariff_{2001} \times Post_{2001}$	−0.0154***	−0.0119***	−0.0091	−0.0054	−0.0197	−0.0219
	(0.0032)	(0.0043)	(0.0063)	(0.0041)	(0.0131)	(0.0144)
Predetermined variables × $Post_{2001}$	No	Yes	No	Yes	No	Yes
Other policy variables	No	Yes	No	Yes	No	Yes
Enterprise control variables	No	Yes	No	Yes	No	Yes
Sample size	204,646	191,900	201,942	189,369	171,621	161,427
Adjusted R^2	0.831	0.842	0.794	0.805	0.757	0.765

Table 11. Effect of trade liberalization on enterprises' wastewater, waste gas and COD emission intensity



Note(s): Calculate the differences between the 90th and 10th percentiles of SO_2 emission intensity (logarithm) of enterprises in three-digit industries and then plot their distribution; plot the distribution of TFP differences among enterprises in the same way, where the vertical line perpendicular to the x-axis indicates the mean of the distribution

Figure 7.
Heterogeneity of enterprises' SO_2 emission intensity (logarithm) and TFP (estimated by OP method)

However, neither NTC nor BTC can be observed directly in the data, and they need to be estimated or indicated by proxy variables. In the settings by Olley and Pakes (1996) (referred to as OP) and Levinsohn and Petrin (2003) (referred to as LP), the production function is in Cobb–Douglas form. Thus, the enterprise efficiency estimated based on these methods can be used to represent NTC. However, consistent estimation of BTC is a major difficulty in the existing literature. Hence, the ratio of input factors is used in this paper to represent BTC indirectly. For a more clear illustration, the following production function is considered.

$$Y = A\left[\rho(A_K \cdot K)^{\frac{\sigma-1}{\sigma}} + (1-\rho)(A_Z \cdot Z)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{3}$$

where Y represents output, K for capital factor and Z for pollution emissions (corresponding to enterprises' SO_2 emissions in this paper); A represents NTC, while A_K and A_Z for BTC; ρ indicates the relative importance among input factors, and σ is the elasticity of factor substitution. Two points about the production function in Eq. (3) should be noted: Firstly, the inclusion of pollution emissions as an input factor is essentially equivalent to the setting of pollution as a by-product (Copeland and Taylor, 2004; Chen, 2009). Secondly, the labor factor L is not included in Eq. (3); adding L or replacing K with L directly will not influence the analysis below.

If r represents enterprises' capital cost and P_Z represents the cost of pollution emissions, their profit π can be expressed as:

$$\pi = Y - rK - P_Z Z \tag{4}$$

The first-order optimization condition for the profit maximization of enterprises is:

$$A\left[\rho(A_K\cdot K)^{\frac{\sigma-1}{\sigma}}+(1-\rho)(A_Z\cdot Z)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}\rho(A_K\cdot K)^{-\frac{1}{\sigma}}A_K=r \quad (5)$$

$$A\left[\rho(A_K\cdot K)^{\frac{\sigma-1}{\sigma}}+(1-\rho)(A_Z\cdot Z)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{1}{\sigma-1}}(1-\rho)(A_Z\cdot Z)^{-\frac{1}{\sigma}}A_Z=P_Z \quad (6)$$

Equations (5) and (6) are further consolidated to obtain:

$$\frac{Z}{K}=\left[\frac{\rho}{1-\rho}\left(\frac{A_K}{A_Z}\right)^{\frac{\sigma-1}{\sigma}}\frac{P_Z}{r}\right]^{-\sigma} \quad (7)$$

Equation (7) indicates that there is a correlation between the ratio of input factors and BTC for a given input factor price, which explains the reason why the ratio of input factors can be used to express BTC. Table 12 shows the effects of trade liberalization on NTC (columns 1 and 2) and BTC (columns 3 to 6). Among them, *TFP_OP* and *TFP_LP* represent the TFP estimated by OP and LP methods to measure NTC, respectively; *lnZK* and *lnZL* represent the logarithm of the ratio of enterprises' SO_2 emissions to capital and labor factors to measure BTC, respectively. The results in columns 1 and 2 indicate that trade liberalization has no significant effect on NTC, whereas columns 3–6 indicate that trade liberalization has a significant effect on BTC. Capital factor price (*Inerest_Rate*, expressed as the interest rate) and labor factor price (*lnWage*, expressed as the logarithm of workers' wages) are added in columns 4 and 6, respectively, to control for the potential deviation between the input factor ratio and BTC in Eq. (7) due to changes in factor prices. It should be noted that the regressions do not control for enterprises' pollution emission price P_Z because, firstly, data on this variable are not available currently, and secondly, compared to capital or labor factor prices, the differences in pollution emission prices of enterprises in the same industry are relatively small and thus can be effectively controlled through industry FE.

6. Extended discussion

This section further discusses the heterogeneous effect of trade liberalization on enterprises' SO_2 emission intensity. In general, if trade liberalization does significantly reduce enterprises' SO_2 emission intensity, enterprises more significantly affected by trade liberalization should

	(1)	(2)	(3)	(4)	(5)	(6)
	NTC		BTC			
	TFP_OP	*TFP_LP*	*lnZK*	*LnZK*	*lnZL*	*LnZL*
$\Delta Tariff_{2001}\times Post_{2001}$	−0.0013	0.0010	−0.0248***	−0.0246***	−0.0215***	−0.0205***
	(0.0035)	(0.0040)	(0.0036)	(0.0036)	(0.0064)	(0.0062)
Inerest_Rate				−0.0001***		
				(0.0000)		
lnWage						0.3165***
						(0.0113)
Predetermined variables $\times Post_{2001}$	Yes	Yes	Yes	Yes	Yes	Yes
Other policy variables	Yes	Yes	Yes	Yes	Yes	Yes
Enterprise control variables	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	184,887	184,891	167,147	166,668	167,312	166,949
Adjusted R^2	0.734	0.803	0.859	0.859	0.867	0.874

Note(s): In the regressions in columns 1 and 2, TFC is the explained variable and thus excluded from the control variables

Table 12. NTC and BTC

have a greater decrease in their SO_2 emission intensity. Intuitively, those enterprises with higher export intensity should be more affected by trade liberalization. In addition, under the same condition of other given factors, the larger the size of the enterprise, the more it will be affected by trade liberalization. This is because enterprises need to overcome certain fixed costs to reach and serve international markets, which means that the larger the enterprise, the less the unit cost of reaching and serving international markets, that is, there is an incremental payoff effect of scale, and thus the greater the impact of trade liberalization (Roberts and Tybout, 1997; Melitz, 2003. Cherniwchan, 2017). In view of this, this paper empirically investigates the effect of trade liberalization on the SO_2 emission intensity of enterprises with various export intensities and scales based on the difference in difference in differences (DDD) model. The regression results indicate that the effect of trade liberalization on reducing SO_2 emission intensity is more significant for enterprises with higher export intensity and larger scale [2].

7. Concluding remarks

China's economic and social development has entered a new period. To meet the growing needs of the people for a better life, the CPC and the state have paid more attention to trade and environmental issues than ever. In this context, this paper explores the intrinsic relationship between trade and environmental pollution in China systematically. The findings of this paper include the following. The reduction in trade barriers significantly reduces the emission intensity of enterprises' main pollutant SO_2 in China, and this conclusion still holds in a series of robustness tests. For every unit reduction in trade barriers (or every unit increase in trade liberalization), enterprises' SO_2 emission intensity decreases by 2.16%. Further mechanism analysis indicates that the reduction in enterprises' SO_2 emission intensity is mainly due to the decrease in their pollution emissions rather than the decrease in their output; the decrease in enterprises' pollution emissions is mainly due to their cleaner production processes rather than end-of-pipe pollution treatment. Moreover, the decrease in coal use intensity is a crucial mechanism for the reduction in SO_2 emission intensity due to trade liberalization; regarding the technical effect of trade barrier changes affecting enterprises' SO_2 emission intensity, BTC rather than NTC is dominant.

The research conclusions of this paper have important policy implications. Firstly, facing the current instability and uncertainty in the world trade landscape, China has been steadfastly expanding its opening-up to the outside world and remains committed to building an open world economy and upholding the multilateral trading system. The research findings indicate that trade is conducive to reducing environmental pollution and can enhance the welfare of Chinese society by improving environmental conditions in addition to the economic growth mechanism identified in classical literature, which provides new and strong support for promoting the construction of a strong trading power in the new era. Secondly, with the continuous improvement of living standards, the people have higher demands for environmental quality, which is increasingly contradictory to the environmental pollution problems arising from the economic development process. To meet their growing needs for a better life, the Report to the 19th National Congress of CPC listed pollution prevention and treatment as one of the three tough battles to secure a decisive victory in building a moderately prosperous society in all respects. However, how to prevent and control pollution effectively is still a widely debated issue. Essentially, the environmental pollution problem is about the economic development model. Although the "one-size-fits-all" approach of large-scale shutdowns of enterprises with high energy consumption and pollution emissions can improve the environment in the short term, it will drag down the economic growth in the long term, which will ultimately harm people's welfare. This study provides new ideas for pollution prevention and treatment; that is, in addition to the direct implementation of environmental regulations, the government can also reduce environmental pollution by expanding opening-up, which is conducive to economic growth, and ultimately achieve win-win development of both the economy and the environment.

Notes

1. Thank the reviewers for their constructive opinions.
2. Due to space limitations, specific results are not reported in this paper and are available to interested readers upon request to the author, who may also refer to the working paper version of this paper published in *Economic Research Journal.*

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