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Trade Openness and Environmental Pollution Management: Push or Pull?

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Abstract: Foreign trade, as one of the troika of China's economic development, plays a vital role, bringing great benefits to the country through trade, but also accompanied by a series of environmental problems such as the export industry's carbon emissions increasing year by year and a series of environmental problems. Therefore, to explore the impact of trade openness on the environmental pollution control mechanism has practical and theoretical significance. Based on relevant theories and literature, this paper first combed through the mechanism of trade opening on environmental pollution and found the entry point. Then, based on the panel data of 30 provinces in China from 2007 to 2017, this paper explored the mechanism of trade opening on environmental pollution in the whole country and the eastern, central and western regions of China, and introduced technological innovation intermediary variables to build an intermediary model. The empirical results show that the relationship between the level of trade openness and industrial wastewater emissions is inverted "N", "U" with industrial sulphur dioxide emissions and negative linear with industrial soot emissions; trade openness will exert a mediating effect on environmental pollution control through technological innovation as a mediating variable.

Keywords: Trade openness, Environmental pollution.

1. Introduction

Since 1978, China has experienced more than 40 years of rapid growth, and its GDP has jumped to the second place in the world. After joining the WTO, China's trade openness has been continuously improved, and its links with the world in economic, financial, cultural and other aspects have been deepened. According to the data of the China Statistical Yearbook, China's total trade volume in 2018 was $4.62 trillion, accounting for 11.75% of the world's total trade volume, and it is the world's largest trading country. Trade openness has played an irreplaceable role in China's economic development. Although trade openness has brought great benefits to our country, it is also accompanied by a series of environmental problems, such as carbon emissions and exhaust emissions of the export industry increasing year by year. According to the 2018 report on the accounting and development of China's economic and ecological GDP released by the Ministry of ecology and environment, the cost of pollution losses in China reached 2trillion yuan in 2015, and the problem of environmental pollution control is urgent. The 17th CPC National Congress proposed the concept of ecological civilization; The 18th CPC National Congress proposed the "five in one" of ecological civilization construction; The 19th CPC National Congress emphasized that the construction of ecological civilization is the millennium plan for the sustainable development of the Chinese nation. Pollution prevention and control is listed as one of the three major battles to build a well-off society in an all-round way. Therefore, in this context, it is of great significance to study the impact mechanism of trade openness on China's environmental pollution, optimize the trade structure, reduce environmental pollution, and achieve sustainable economic growth.

Foreign theories on the relationship between trade and environment originated from the "pollution paradise" hypothesis, which has led to heated discussions among foreign scholars. This paper summarizes its main points as follows. First, the development of trade has aggravated environmental pollution. Ekins et al. (1994) believed that the development of trade and frequent international transportation would increase pollutant emissions; Dua and Esty (1997) believe that in the context of globalization, countries will reduce environmental standards and enhance their competitiveness, resulting in the phenomenon of "race to the bottom line"; Aklin (2016) and Andersson (2017) believe that in order to obtain benefits through trade openness, developing countries reduce their own environmental standards, thereby exacerbating environmental pollution.

Second, trade will improve the environment. Lucas et al. (1992) studied the impact of trade openness on the growth rate of output toxicity intensity, and found that in a rapidly growing economy, the increase of trade openness will reduce the growth rate of output toxicity intensity; Based on the act model, antweiler et al. (2001) found that trade can reduce environmental pollution by analyzing the panel data of 43 developing and developed countries; Mcausland (2008) and beladi and oladi (2011) believe that the development of trade promotes technology diffusion, which can effectively reduce environmental pollution; MC Ausland and Millimet (2011) confirmed that foreign trade can reduce pollutant emissions by analyzing the different impacts of domestic trade and foreign trade on the environment.

Third, the impact of trade openness on environmental pollution is complex. Grossman and Krueger (1991) explored the impact of foreign trade on the environment by analyzing the scale effect, structure effect and technology effect, and then found that the scale effect is negative, the structure effect is not clear, and the technology effect is positive, so they cannot simply think that trade promotes or worsens the environment; Gale and Mendez (1998) analyzed the relationship between trade, income growth and environment, and then found that the increase of income has an adverse impact on environmental quality, but the impact of trade liberalization on pollution is not significant; Dean (2002) examined the impact of trade liberalization on environmental damage and found that the improvement of openness to the international market aggravated environmental damage through the terms of trade, but reduced environmental damage through income growth; Cole and Elliott (2003) found that the empirical results of the relationship between trade and environment vary with different pollutants; Atici (2012) found that import trade will not worsen Japan's environment, but it is the opposite for China, that is, the relationship between trade and environment will be different based on different samples.

This paper fully understands the research results of Chinese scholars on the relationship between trade openness and environmental pollution, and summarizes its research directions as follows. First, the relevant theoretical and empirical analysis is carried out around whether the "pollution refuge" hypothesis is applicable in China. Xia Youfu (1999), you Weimin (2010), Zhang Yu and Jiang Dianchun (2014) believed that opening up had caused China's industrial structure to shift to pollution intensive industries, and the "pollution refuge" hypothesis had been verified in China. Dang Yuting (2010), Hu Zhaolian and Shi Daqian (2019) concluded that foreign trade had a negative impact on the environment. Nie Fei and Liu Haiyun (2015) believe that the introduction of foreign capital can effectively reduce the pollution level and has the "pollution halo" effect. Dai Lihua and Lin Faqin (2015) found that the increase of foreign trade dependence can reduce industrial sulfur dioxide emissions.

Second, analyze the impact of trade on the environment. Chen Lili (2004) proposed that the impact of trade on the environment can be divided into scale effect, income effect, structure effect, product and technology effect and environmental supervision effect, and also analyzed the impact of environmental protection on trade with the help of H-0 factor endowment; Through empirical analysis, Dang Yuting and magnum (2007) found that the technical effect and structural effect of trade on the environment are positive, and the larger negative scale effect makes trade opening still have an adverse impact on the environment; Zhuanghuiming et al. (2009) found that the reduction of technology effect, the intensification of scale effect, the instability of structure, and the overall opening of trade are conducive to the improvement of China's environmental problems.

Thirdly, the relationship between trade and environmental pollution is analyzed from the perspectives of institutional factors, corruption degree and technological innovation. Laimingyong et al. (2005) empirically verified the technology spillover effect of export trade and foreign direct investment; Kazuo University and Lu Lianju (2015) believe that when the level of corruption is low, trade plays a role in promoting environmental governance, and when corruption reaches a certain level, trade shows resistance to environmental governance; Kan University and Lu Lianju (2016) used the panel smooth transition regression model to obtain empirical results: for the environmental pollution effect of import and export trade, technological progress and environmental regulation play a negative effect; Liu Jiayue et al. (2017) analyzed that the institutional improvement brought by market-oriented reform can reduce the environmental pollution effect of trade opening.

In general, there is a great controversy in the current academic circles about whether trade opening is conducive to the governance of environmental pollution. Some scholars believe that trade opening helps reduce environmental pollution, others believe that trade opening intensifies environmental pollution, and others believe that trade opening has positive and negative effects on environmental pollution, and its net effect on the environment should be investigated. However, there are few studies on establishing a nonlinear model to analyze the inverted "U" relationship between trade openness and environmental pollution. Secondly, when most studies explore the impact of trade on the environment in combination with other factors, they mostly use the threshold model (taking other factors as threshold variables) or study the interaction between trade and other factors on the environment, and less explore the internal impact mechanism of trade on the environment. This paper will establish an intermediary model, taking technological innovation as intermediary variables to explore the impact mechanism of trade openness on environmental pollution control.

From a theoretical point of view, based on the two-way FE model, maximum likelihood estimation, panel correction standard error and other measurement methods, this paper establishes a benchmark model to test the impact of trade opening on environmental pollution. Combined with the eastern, Western and central regions to analyze regional differences, this paper introduces intermediary variables to analyze the internal impact of trade opening on environmental pollution. It has certain theoretical significance to further improve the existing academic research framework on trade openness and environmental pollution.

From a practical point of view, combined with the content of China's 13th five year plan, the development of environmental protection industry needs to be combined with China's reality and deepen international cooperation, and the strengthening of policy support also needs to be paid attention to at the same time. In the context of international cooperation, in order to better serve the establishment of a resource-saving and environment-friendly society in China, it is essential to strengthen environmental pollution control. Moreover, under the premise that the unstable factors of the global economy still exist, how to seize the opportunity of economic globalization, how to improve the trade structure, and how to achieve the sustainable and healthy development of China's economy is of great significance. Through empirical analysis, this paper aims to provide practical suggestions for trade opening to play a driving role in environmental pollution control.

What impact will trade openness have on environmental pollution control? Is it thrust or resistance? Does trade openness have a direct or indirect effect on environmental governance? Is technological innovation an intermediary variable for trade openness to affect environmental pollution control? In order to answer this series of questions, firstly, this paper analyzes the current situation combined with the specific situation of China's trade and environmental pollution, and then uses the inter provincial panel data to carry out an empirical study on the relationship between trade openness and environmental pollution. Combined with the existing research results, this paper finds that scholars use different data and different estimation methods to analyze the relationship between trade openness and environmental quality is different. Based on this, this paper adopts a variety of measurement methods, such as maximum likelihood estimation and two-way FE model, in order to obtain scientific and robust empirical results. In addition, taking technological innovation as the intermediary variable, this paper constructs a model to analyze the internal impact mechanism of trade openness on environmental pollution control. Strive to make contributions to the scientific research on improving trade openness and environmental pollution, and also provide some reference for the follow-up pollution control work.

The research purpose of this paper is to use the panel data of 30 provinces in China from 2007 to 2017 for regression analysis, explore the impact mechanism of trade openness and environmental pollution control and the regional differences of trade openness on environmental pollution control, and then summarize the results of empirical analysis, and put forward some suggestions in combination with the current international and domestic situation.

The research content of this paper is divided into the following four parts. Part I: introduction. This part introduces the research background, research significance, specific analysis methods, analysis framework, and puts forward the innovation of the research. Part II: methodology. This paper reviews the literature at home and abroad from the two aspects of environmental pollution, trade openness and environmental pollution, finds the entry point and puts forward the research hypothesis based on the research of existing scholars. Part III: results and discussion. On the basis of EKC curve, establish a nonlinear model of trade openness and environmental pollution, select appropriate proxy variables, collect the panel data corresponding to each province from 2007 to 2017, select panel estimation methods such as maximum likelihood estimation and two-way FE model, and conduct full sample and regional regression analysis. An intermediary model is also established to test the internal impact mechanism of trade openness on environmental pollution control. Part IV: conclusion. Through the summary and analysis of the empirical results of this paper, we get relevant conclusions and put forward reasonable suggestions for this.

2. Methodology

2.1. Theoretical basis

In the 1970s, trade and environmental pollution gradually attracted widespread attention in the world. Environmentalists in some countries believed that although the development of trade would promote economic development, it would worsen their own environment, especially in countries or regions with backward economic development. Since Grossman and Krueger (1991) put forward the "three effects" analysis, many scholars have tried to study the impact of trade openness on the environment. Academic circles have also put forward two important theoretical hypotheses: factor endowment hypothesis and pollution paradise hypothesis, which explain the different directions of structural effects from the perspective of comparative advantage of trade. The theory of trade openness and environmental pollution has been constantly improved.

2.1.1. Comparative advantage theory

This theory was put forward by David Ricardo. If the opportunity cost of a country producing a product is lower than that of other countries, that country has a comparative advantage in the production of that product. The theory of comparative advantage holds that a country should export products with comparative advantages and import products with comparative disadvantages. Developing countries have comparative advantages in the production of primary industrial products, while developed countries have comparative advantages in high-tech products. According to the theory of comparative advantage, developing countries should export primary manufactured goods and import high-tech products.

2.1.2. Pollution paradise hypothesis

The pollution paradise hypothesis was put forward by Walter and ugelow (1979), which believes that in the opening of trade between countries, pollution intensive industries tend to be established in countries or regions with relatively low environmental regulations. If a country has relatively loose environmental regulation standards, it has a comparative advantage in pollution intensive products, and tends to export pollution intensive products in a short time, aggravating its environmental pollution.

2.1.3. Factor endowment hypothesis

This hypothesis holds that different countries have different factor endowments, and different factor prices in different countries lead to differences in production costs and commodity prices in different countries. In international trade, a country should export factor intensive products and import factor scarce products. Generally speaking, developing countries have rich natural resources and labor resources, and developed countries have rich capital. Therefore, developing countries should export labor-intensive products, and developed countries should export capital intensive products.

2.2. Research hypothesis

By analyzing the existing scholars' research results on trade openness and environmental pollution, it is found that the impact of trade openness on environmental pollution control is uncertain, not just a simple linear relationship. Grossman and Krueger (1991) studied the impact of trade opening on the environment, which is divided into scale effect, structure effect and technology effect. Scale effect refers to the expansion of economic scale and the increase of pollutant emissions due to the opening of trade. Technology effect refers to that while trade increases income, people's preference for environmental quality increases. The government formulates stricter environmental policies to force enterprises to use cleaner production technologies and reduce pollutant emissions. Structural effect refers to the change of a country's industrial structure caused by trade opening, and the impact on pollution is uncertain. In the context of trade opening, economically backward countries or regions have to reduce their environmental standards for their own development, leading to the transfer of high polluting low-end industries to their own markets, and the scale effect of trade opening intensifies pollutant emissions. However, with the improvement of trade level and the continuous improvement of foreign advanced technology, trade flows into the domestic market, and then through the maturity of domestic technology absorption capacity, continue to promote the transformation of production mode and the improvement of environmental management level, the technical and structural effects brought by trade opening should be able to achieve the effective treatment of domestic environmental pollution. Based on this, this paper proposes hypothesis 1.

H_1: The relationship between trade openness and environmental pollution presents an inverted "U" shape, that is, in the short term of trade development, the improvement of trade level intensifies environmental pollution, and in the long term, foreign trade will inhibit environmental pollution.

Coe and Helpman (1993) estimate that foreign R & D has a beneficial impact on domestic productivity, and this impact is stronger when an economy is more open to foreign trade. Jakob b.madsen (2005) used the 120 year data of OECD countries to explore the technology spillover effect of trade exchanges. It is estimated that in the past century, the import of knowledge has increased total factor productivity by nearly 200%. Hu Zhaolian and Shi Daqian (2019) mentioned that trade openness can have a positive impact on technological innovation, promote the upgrading of manufacturing in developing countries, and then improve the level of environmental pollution. The development of international trade has brought benefits of technology spillover to our country, which affects the improvement of our environmental pollution control technology and reduces the level of environmental pollution. The impact effect of trade opening on the environment can be divided into direct effect and indirect effect. The indirect effect follows the "trade technological progress environmental governance", and the direct effect is the direct impact of trade opening on environmental pollution. Based on this, put forward hypothesis 2.

H_2: Trade openness indirectly affects environmental pollution control through technological innovation.

2.3. Benchmark model

Similar to the existing literature, using the practice of Peng Shuijun and Bao Qun (2006) for reference, the simplified regression equation is used for analysis:

$$y_{it}=\beta_0+\beta_1 x_{it}+\beta_2 x_{it}^2+\beta_3 x_{it}^3+\beta_4 z_{it}+\mu_{it} \quad (1)$$

Where, y_{it} refers to the pollutant emission of the ith Province in year t; Xx_{it}represents the trade opening level of the ith Province in the t year; z_{it} represents other control variables that affect environmental quality; β_0 Refers to specific individual effects. According to equation (1), several possible curve relationships between trade and environmental quality can be judged: first, if $\beta_1>0$、$\beta_2<0$、$\beta_3>0$ is a cubic curve, that is, an n-shaped curve; Second, if $\beta_1<0$、$\beta_2>0$、$\beta_3<0$ shows an inverted n-shaped curve relationship; Third, $\beta_1>0$、$\beta_2<0$、$\beta_3=0$ is a conic relationship, that is, an inverted U-shaped curve relationship; Fourth, $\beta_1<0$、$\beta_2>0$、$\beta_3=0$ is a U-shaped curve relationship; Fifth, if $\beta_1\neq0$、$\beta_2=0$、$\beta_3=0$ is linear. The specific model construction is as follows:

$$pwater_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\mu_{it} \quad (2)$$

$$pso2_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\mu_{it} \quad (3)$$

$$psmoke_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\mu_{it} \quad (4)$$

Where i is the province (i=1、…30) and t is the time (t = 2007, 2008,... 2017). Environmental pollution indicators include industrial waste water emissions($pwater_{it}$), industrial sulfur dioxide emissions($pso2_{it}$), and industrial smoke and dust emissions($psmoke_{it}$). $open_{it}$ refers to the degree of trade dependence.

In this paper, control variables are added and the model is built as follows. Where, $pgdp_{it}$ is the per capita GDP variable, reg_{it} is the environmental regulation variable, pop_{it} is the population density variable, $market_{it}$ is the marketization degree variable, $industry_{it}$ is the industrial structure variable, and fdi_{it} is the foreign direct investment variable.

$$pwater_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\beta_4 pgdp_{it}+\beta_5 reg_{it}+\beta_6 pop_{it}+\beta_7 market_{it}+\beta_8 industry_{it}+\beta_9 fdi_{it}+\mu_{it} \quad (5)$$

$$pso2_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\beta_4 pgdp_{it}+\beta_5 reg_{it}+\beta_6 pop_{it}+\beta_7 market_{it}+\beta_8 industry_{it}+\beta_9 fdi_{it}+\mu_{it} \quad (6)$$

$$psmoke_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\beta_4 pgdp_{it}+\beta_5 reg_{it}+\beta_6 pop_{it}+\beta_7 market_{it}+\beta_8 industry_{it}+\beta_9 fdi_{it}+\mu_{it} \quad (7)$$

The estimation steps are as follows: first, the model simultaneously introduces the square term and the cubic term of the trade openness level to estimate, and judges whether there is an n-type or inverted n-type relationship between trade openness and environmental pollution according to the t-statistics, Z-statistics and Wald test. If the three terms of the level of trade openness are not significant, the three terms shall be removed and re-estimated.

In order to ensure the robustness and reliability of the results, the FE model, the panel corrected standard error (PCSE) method, the maximum likelihood estimation (MLE) method and the random effect model are used to perform regression estimation for the equation. Panel correction standard error (PCSE) can prevent heteroscedasticity, cross-sectional correlation and error autocorrelation. The fixed effect model is a two-way fixed effect model that controls individual and time effect, and Driscoll kraay standard error is introduced into the model.

2.4. Variable selection and data source

(1) Explained variable: degree of environmental pollution

According to the research of existing scholars on the relationship between trade opening and environmental pollution, most of the selected environmental pollution indicators are industrial SO_2 emissions or environmental pollution data such as industrial "three wastes" to calculate the comprehensive calculation index. However, considering the limitations of a single indicator and the fact that the weighted average cannot guarantee the scientific integrity, this paper selects three indicators: industrial wastewater discharge, industrial SO_2 discharge and industrial smoke and dust discharge, and takes them as the explanatory variables for regression analysis. In terms of data processing, this paper uses per capita industrial wastewater discharge (pwater) to measure water pollution, per capita industrial SO_2 discharge (pso2) and per capita industrial smoke and dust discharge (psmoke) to measure air pollution.

(2) Core explanatory variable: Trade Openness(open)

Based on the practice of Bao Qun (2008), this paper selects the proportion of the total import and export volume of each province (region) to the regional GDP as the variable to measure the level of trade openness. Among them, the total import and export volume of each province (region) is converted into RMB through the average annual exchange rate of the Bureau of statistics.

(3) Other explanatory variables

In order to avoid omission of variables, this article introduces the following six control variables:

Per capita Gross Domestic Product (pgdp). This indicator is used to measure the level of economic development in a region based on per capita GDP.

Environmental regulation (reg). This article uses Cole and Elliott's method, which considers the proportion of SO2 emissions to industrial value-added as an indicator of the intensity of environmental regulation. The higher the value of this indicator, the more SO2 is emitted per unit of industrial value-added, indicating a lower intensity of environmental regulation.

Degree of marketization (market). Borrowing from Shao Shuai's (2019) method, the proportion of non-state-employed workers to total employed workers is used as an indicator of the degree of marketization. A higher degree of marketization is beneficial to improving resource allocation efficiency and energy efficiency (Shao et al., 2011).

Industrial structure (industry). The proportion of value added in the secondary industry to regional GDP is used to reflect the impact of changes in industrial structure on environmental pollution. Regardless of foreign developed countries or China's own economic development process, the development of the industrial sector, especially energy-intensive and highly polluting industries, has brought about a large amount of industrial pollutant emissions, causing harm to the environment.

Foreign direct investment (fdi). This article borrows from Lu Fengzhi's method and uses the actual foreign direct investment used in each province as an indicator of the level of foreign direct investment. This amount is converted into per capita foreign direct investment (fdi) using the annual average exchange rate of the Statistical Bureau. Some countries may blindly attract foreign direct investment and relax capital control requirements, thereby directing funds to certain resource and capital-intensive industries, while bearing the consequences of environmental pollution alone while enjoying the economic benefits brought by foreign direct investment.

Population density (pop). Population density is introduced into the control variable system. This indicator can explain the impact of population size on environmental pollution. On the one hand, a larger population size will consume more resources and emit more pollutants. On the other hand, a higher population density will lead to more people realizing the importance of protecting the environment, the environmental impact results having uncertainties and a close relationship with the level of regional economic development.

(4) Mediating variable: technological innovation (tech)

This article uses the number of patent authorizations as an indicator of technological innovation. Given the low correlation between the number of design patents authorized and environmental pollution, the sum of authorized invention patents and utility model patents is used as the measure of technological innovation.

Based on the availability of relevant data and consistency of statistical methods, this article selects panel data from 30 provinces in China between 2007 to 2017 as the sample for empirical analysis. Due to severe data missing in Tibet, data from this region were excluded. A total of 30 provinces in China were selected for analysis. Environmental pollution data for the 30 provinces from 2007-2015 (pwater, pso2, psmoke) were obtained from the "China Environmental Statistical Yearbook", while data for the years 2016 and 2017 were obtained from the "China Urban Statistical Yearbook". Data on trade openness (open), per capita Gross Domestic Product (pgdp), environmental regulation (reg), industrial structure (industry), population density (pop), and technological innovation (tech) were sourced from the National Bureau of Statistics website. Data on foreign direct investment (fdi) were obtained from provincial statistical yearbooks. Data on the degree of marketization (market) were obtained from the "China Labor Statistical Yearbook". Descriptive statistics of each variable are shown in the table below.

Table 1. Descriptive statistics

Variable	Unit	Observation	mean value	standard deviation	minimum value	Maximum value
Pwater	Ton/person	330	14.77	8.34	0.60	47.63
Pso2	Kg/person	330	14.43	11.29	0.12	60.70
Psmoke	Kg/person	330	9.68	7.93	0.20	38.73
Open		330	0.30	0.36	0.02	1.72
Pgdp	10000 yuan/person	330	4.26	2.38	0.79	12.90
Fdi	100 million yuan/10000 people	330	0.11	0.14	0.00	0.85
Pop	10000 people/square kilometer	330	0.28	0.12	0.06	0.60
Reg	Kg/10000 yuan	330	15.04	16.43	0.22	140.48
Market		330	0.69	0.12	0.35	0.92
Industry		330	0.46	0.08	0.19	0.59
tech	term	330	2.26	3.29	0.01	21.48

3. Results and Discussion

3.1. Full sample estimation results

Firstly, before conducting the formal panel data regression analysis, it is necessary to test for the presence of multicollinearity. Through mixed OLS regression, the variance inflation factors (VIF) of each explanatory variable were computed as shown in Table 2. The maximum VIF value of the variable Pgdp was 3.32, which is less than 10, indicating that there is no need to consider multicollinearity issues.

Table 2. Variance inflation factor for each explanatory variable

Variance	Open	Pgdp	Fdi	Pop	Reg	Market	Industry
VIF	2.02	3.32	2.77	1.17	1.53	1.92	1.27

This article employs fixed effects models with individual and time effects, the panel-corrected standard errors (PCSE) estimation, maximum likelihood estimation (MLE) and random effects models to regress equations (2), (3), (4), (5), (6), and (7), respectively, in order to ensure the robustness of the regression estimates. The specific regression results and analyses are presented below. The numbers within parentheses in the regression results correspond to T statistics for FE models and Z statistics for PCSE, MLE, and RE models. The statistical measures in the tables correspond to F statistics for FE models, Wald statistics for RE and PCSE models, and LR statistics for MLE models. *** , ** , and * correspond to significance levels of 1%, 5%, and 10%, respectively.

(1) Regression estimation of industrial wastewater emissions (pwater)

Table 3. Regression results of industrial wastewater discharge and trade openness level

Variance	model 1 FE	model 2 FE	model 3 PCSE	model 4 PCSE	model 5 MLE	model 6 MLE	model 7 RE	model 8 RE
Open	-38.85 *** (-4.55)	-44.73*** (-6.06)	15.49 *** (3.67)	13.20*** (2.71)	-24.76 *** (-2.72)	-36.88*** (-4.08)	-18.63 ** (-2.17)	-27.98*** (-3.02)
(Open)2	49.70 *** (6.49)	50.91*** (7.63)	-7.24 *** (-2.64)	-6.23** (-2.49)	37.66 *** (3.22)	47.22*** (4.02)	31.74 *** (2.71)	39.26*** (3.20)
(Open)3	-18.08 *** (-8.49)	-17.63*** (-9.78)			-14.74 *** (-3.29)	-17.19*** (-3.86)	-12.99 *** (-2.85)	-15.08*** (-3.21)
Pop		-1.51 (-0.27)		-8.63*** (-3.11)		-3.32 (-0.75)		-5.29 (-1.19)
Pgdp		-1.30*** (-5.74)		-0.10 (-0.26)		-0.88** (-2.20)		-0.72* (-1.86)
Reg		-0.02 (-1.05)		0.02 (1.18)		-0.01 (-0.72)		-0.01 (-0.32)
Market		26.08*** (10.48)		19.32*** (3.43)		27.43*** (4.99)		28.64 *** (4.96)
Industry		-24.69*** (-4.85)		31.24*** (4.31)		-19.80*** (-2.71)		-9.62 (-1.36)
Fdi		8.27** (2.81)		-3.87 (-1.02)		7.56* (1.91)		5.63 (1.33)
Statistic	35.96	13457.35	21.85	1444.60	196.89	229.60	254.10	286.51
R^2	0.4938	0.5494	0.4944	0.5632			0.0879	0.1719

When the indicator for environmental pollution is the industrial wastewater discharge, the regression estimation results are shown in Table 3. By comprehensively analyzing the FE model, RE model, PCSE model, and MLE model, it was found that the trade development level and industrial wastewater discharge showed an inverted "N" relationship. Therefore, the null hypothesis 1 was rejected at the level of the industrial wastewater discharge (pwater) indicator. The three variables in Model 1 - trade openness level (Open), its square term$(Open)^2$, and its cubic term$(Open)^3$ - all passed the significant test at the 1% level. The coefficient of the trade openness level was negative, the coefficient of the trade openness level's square term was positive, and the coefficient of the cubic term was negative. That is, the trade openness and environmental pollution showed an inverted "N" pattern. Furthermore, after controlling for variables, it was found that the coefficient of the trade openness level was still significant in Model 2. Additionally, the MLE model and RE model produced the same empirical results, indicating robustness. The inverted "N" relationship between the trade openness level and environmental pollution may be due to China's development strategy in the 1950s, which prioritized heavy industry. Because of the lack of relevant technological conditions, resources were allocated irrationally, and industrial waste discharge could not be effectively treated. After the reform and opening up, foreign trade began to develop. By importing some capital-intensive products based on comparative advantages, and exporting primarily labor-intensive products such as textiles, the beneficial effects of import were greater than the adverse effects of exporting on the environment, thus playing a certain restraining role in industrial wastewater discharge. Then, as the trade continued to expand, developed countries transferred some low-end industries with high pollution and other factors to China, leading to an increase in industrial pollutant emissions. With the long-term development of foreign trade and increasing levels of openness, domestic industrial sectors have undergone rapid development, stimulating the development of industrial clusters. With the continuous increase in the degree of industry agglomeration and collaborative cooperation, high-pollution industries have gradually been eliminated, promoting the optimization and upgrading of China's industrial structure. In addition, cutting-edge technology will spread to domestic industries as international trade develops, and people's demand for clean products will also increase, leading to a downward trend in environmental pollution emissions.

For other explanatory variables, the coefficient of per capita gross domestic product (pgdp) is significantly negative in FE, MLE, and RE models, indicating that the level of economic development has a suppressive effect on industrial wastewater discharge. The coefficient of population density (pop) is negative, and only passes the significance test at the 1% level in the PCSE model, indicating that population density plays a suppressive role in industrial wastewater discharge to a certain extent. The coefficient of environmental regulation (reg) is both positive and negative, and none of them passed the significance test, indicating that the impact mechanism of environmental regulation on industrial wastewater discharge is relatively complex. The coefficient of marketization degree (market) is positive, and passes the significance test at the 1% level, indicating that the higher the degree of marketization, the more it will promote the increase of industrial wastewater discharge. The coefficient of industrial structure (industry) in the FE and MLE models passes the significance test at the 1% level and is negative, while the coefficient in the PCSE model passes the significance test at the 1% level and is positive. Foreign direct investment (fdi) has passed the significance test in some models, and the coefficient is positive, indicating that foreign direct investment will increase the discharge of industrial wastewater.

(2) Regression estimation of industrial sulfur dioxide emissions (pso2)

Table 4. Regression results of industrial sulfur dioxide emissions and trade openness level

Variance	model 1 FE	model 2 FE	model 3 PCSE	model 4 PCSE	model 5 MLE	model 6 MLE	model 7 RE	model 8 RE
Open	-17.36 ** (-3.20)	-19.94*** (-6.69)	-15.61 *** (-3.27)	-11.72*** (-2.18)	-18.16 *** (-3.37)	-17.22*** (-3.31)	-18.13 *** (-3.28)	-16.59*** (-3.20)
(Open)2	5.72 *** (4.04)	7.34*** (5.20)	5.21 ** (2.10)	4.81** (1.91)	6.08 ** (2.30)	7.01*** (2.75)	6.06 ** (2.24)	7.24*** (2.70)
Pop		4.67 (1.28)		-7.28*** (-2.19)		1.77 (0.37)		-1.52 (-0.32)
Pgdp		-1.15** (-2.49)		0.95 (1.61)		-0.67 (-1.60)		-0.31 (-0.76)
Reg		0.16* (2.11)		0.32 (3.70)		0.18*** (6.35)		0.20*** (6.81)
Market		27.59*** (3.49)		7.59*** (0.89)		23.49*** (3.95)		18.14 *** (2.97)
Industry		28.69** (2.55)		37.55*** (4.65)		29.40*** (3.88)		32.58*** (4.31)
Fdi		3.76 (0.88)		-2.18 (-0.71)		3.62 (0.85)		2.91 (0.64)
Statistic	8.72	122.51	15.75	221.02	294.47	354.52	475.23	567.42
R^2	0.6187	0.6843	0.5616	0.6931			0.2798	0.4730

Through comprehensive analysis of the FE model, RE model, PCSE model, and MLE model, it was found that the level of trade openness and industrial sulfur dioxide emissions have a "U-shaped" relationship, and therefore reject hypothesis 1 at the level of industrial sulfur dioxide (pso2) indicators. The trade variable (open) in Model 1 passed the significance test at the 5% level, with a negative coefficient, and its squared variable$(\text{Open})^2$ passed the significance test at the 1% level with a positive coefficient, remaining significant after introducing control variables, indicating a "U-shaped" relationship between trade and industrial sulfur dioxide emissions. The coefficients in PCSE, RE, and MLE models are all significant, with the trade variable (open) having a negative coefficient and the squared variable$(\text{Open})^2$ having a positive coefficient. Therefore, the empirical results of the "U-shaped" relationship between trade openness and industrial sulfur dioxide emissions are robust, and when the trade level is low, industrial sulfur dioxide emissions are reduced, and when the trade level is high, industrial sulfur dioxide emissions increase.

The coefficient of population density (pop) passed the significance test at the 1% level in the PCSE model with a negative value, while the coefficients in the FE and MLE models were positive and did not pass the significance test, indicating that the effect of population density on industrial sulfur dioxide is more complicated. The coefficient of per capita gross domestic product (pgdp) in the FE model was significantly negative, indicating that the level of economic development has a suppressive effect on industrial sulfur dioxide emissions. The coefficient of environmental regulation (reg) passed the significance test in the FE, RE, and MLE models, with a positive value, indicating that the lower the degree of environmental regulation, the greater the industrial sulfur dioxide emissions, so effective environmental regulation measures can reduce the emissions of pollutants. The coefficient of marketization degree (market) passed the significance test in the FE, PCSE, RE, and MLE models, with positive values, indicating that the higher the degree of marketization, the more it aggravates the increase of industrial sulfur dioxide emissions. The coefficient of industrial structure (industry) was positive and passed the significance test, indicating that the increase in the proportion of the added value of the secondary industry promotes the increase in industrial sulfur dioxide emissions. The coefficient of foreign direct investment (fdi) did not pass the significance test, possibly due to the complex relationship between foreign direct investment and industrial sulfur dioxide emissions, and the significant regional differences of foreign direct investment.

(3) Regression estimation of industrial smoke and dust emissions (psmoke)

Table 5. Regression results of industrial smoke and dust emissions and trade openness level

Variance	model 1 FE	model 2 FE	model 3 PCSE	model 4 PCSE	model 5 MLE	model 6 MLE	model 7 RE	model 8 RE
Open	-9.09 *** (-3.85)	-4.38 (-1.33)	-14.14 *** (-4.05)	-13.47*** (-3.23)	-11.25 *** (-2.86)	-9.89** (-2.43)	-11.20 *** (-2.80)	-10.78*** (-2.65)
(Open)2	1.70 (1.20)	1.22 (0.64)	4.02 ** (2.22)	4.24** (2.13)	2.56 (1.32)	2.67 (1.34)	2.54 (1.29)	2.99 (1.45)
Pop		5.73 (1.17)		-4.74 (-1.60)		4.19 (1.13)		3.18 (0.85)
Pgdp		0.99*** (4.77)		1.27*** (3.18)		0.67** (2.11)		0.70** (2.18)
Reg		0.03 (1.14)		0.13*** (3.23)		0.04** (2.13)		0.05** (2.39)
Market		9.58 (1.52)		-5.38 (-0.73)		6.58 (1.42)		4.64 (0.98)
Industry		-0.67 (-0.08)		20.43*** (2.60)		7.14 (1.19)		9.83* (1.65)
Fdi		-5.57** (-3.06)		-6.85** (-2.40)		-7.10** (-2.14)		-7.57** (-2.18)
Statistic	15.15	593.76	31.94	63.52	183.85	201.06	239.22	255.36
R^2	0.4450	0.4803	0.4883	0.5452			0.2676	0.3613

Through comprehensive analysis of the FE model, RE model, PCSE model, and MLE model, it was found that there is no inverted U-shaped relationship between trade openness and industrial smoke and dust emissions, but a linear relationship. Therefore, hypothesis 1 is rejected at the level of industrial smoke and dust emissions (psmoke) indicators. From the table, it can be seen that in the PCSE model, MLE model, and RE model, the core explanatory variable, i.e., the trade openness level (Open), has a significant negative coefficient for the first term. Even after introducing control variables, it remained significant, but its squared variable $(\text{Open})^2$ did not pass the significance test for the coefficients in the FE, MLE, and RE models, indicating that there is no curve relationship between trade openness level and industrial smoke and dust emissions. As the trade openness level increases, the emissions of industrial smoke and dust decrease. To further confirm the linear relationship between trade openness and industrial smoke and dust emissions, a fixed-effects model regression including the third-term of trade openness level was conducted for equation (4), and the empirical results are as follows:

$$psmoke_{it}=15.32-7.88open_{it}-0.13open_{it}^2+0.72open_{it}^3 \quad (8)$$

(-1.40) (-0.02) (0.21)

From the empirical results, we can see that the T statistics of the quadratic and cubic terms of trade openness level in equation (8) are not significant. The Wald test of $\beta_2=\beta_3=0$ is 0.78, indicating that the joint significance of the quadratic and cubic terms of trade openness level is rejected. Moreover, compared to Model 1, the T statistics of the trade openness level squared term in equation (8) are less significant after introducing the cubic term of trade openness level. Therefore, based on the above analysis, it can be concluded that there is no curve relationship between industrial smoke and dust emissions and trade openness level.

Environmental regulations (reg) are significant in the coefficient of models RE, PCSE, and MLE, with positive coefficient values, indicating that the lower the environmental regulations, the greater the industrial smoke and dust emissions. The coefficient of industrial structure (industry) is significant and positive in the PCSE and RE models' significance test, while negative in the FE model coefficient, indicating that the impact of industrial structure on industrial smoke and dust emissions is relatively complex. The coefficients of foreign direct investment (fdi) are significant and negative, indicating that foreign direct investment plays a role in suppressing industrial smoke and dust emissions, possibly due to technology spillovers from foreign direct investment, or increased attention to pollution problems caused by the transfer of high-energy, high-pollution industries after a certain stage of FDI inflow, realizing selectively attracting foreign direct investment.

Through a comprehensive analysis of the full-sample regression results of the three environmental pollution indicators, we found that the relationship between the level of trade openness and industrial wastewater discharge presents an inverse "N" shape, a "U" shape relationship with industrial sulfur dioxide emissions, and a negative linear relationship with industrial smoke and dust emissions. Therefore, overall, the improvement in the level of trade openness will suppress environmental pollution. The impact mechanism of population density (pop) on environmental pollution is relatively complex, and it is unclear whether it is a help or a hindrance to environmental pollution control. Per capita GDP (pgdp) will reduce industrial wastewater emissions but increase industrial smoke and dust emissions. The higher the level of environmental regulations (reg), the lower the sulfur dioxide and smoke and dust emissions, indicating that effective regulatory measures can reduce environmental pollution. The higher the level of marketization (market), the more it will aggravate industrial wastewater and sulfur dioxide emissions, indicating that China's marketization mechanism is incomplete and has failed to play its role in improving energy utilization efficiency. The industrial structure (industry) will aggravate industrial sulfur dioxide emissions, indicating that as China's industry develops, pollutant emissions are promoted. Foreign direct investment (fdi) will reduce industrial smoke and dust emissions, reducing pollutant emissions.

3.2. Estimated results by region

In order to further analyze the regional differences of the impact of trade openness on environmental pollution, this article divides 30 provinces into three regions: Eastern, Central and Western. The fixed effect model is used to regressively estimate the industrial wastewater (pwater), industrial sulfur dioxide (pso2), and industrial dust (psmoke) pollution indicators in the three regions.

(1) Regression estimation of industrial wastewater discharge(pwater)

The table below shows the fixed-effect regression estimation results of the trade openness level and industrial wastewater discharge(pwater) in the Eastern, Central and Western regions. In model 1, the coefficient of the trade openness variable(open) is positive and significant, and the coefficient of the square term is negative and significant. After introducing control variables, it is still significant, indicating that the trade openness and industrial wastewater discharge in the Eastern region show an inverted U-shaped relationship. In model 3, the coefficient values of trade openness(open), the square term $(\mathrm{Open})^2$, and the cubic term $(\mathrm{Open})^3$ are negative, positive, and negative, respectively, and all pass the significance test. Even after introducing control variables, they are still significant, indicating that the trade openness and industrial wastewater discharge in the Central region show an inverted N-shaped relationship. In model 5, the coefficients of trade openness(open) and the quadratic term$(\mathrm{Open})^2$ are negative and positive, respectively, indicating that the trade openness and industrial wastewater discharge in the Western region show a U-shaped relationship.

The coefficient value of marketization level (market) in model 4 has passed the significance test at the 1% level, and the coefficient values are all positive, indicating that the increase of marketization level in the Central region will exacerbate the discharge of industrial wastewater. Jia Ming, et al. (2016) found that the higher the degree of marketization, the more frequent the environmental pollution behavior of listed companies in the region through analyzing the regional distribution of environmental pollution behavior of listed companies. The intensification of industries in the Central region, coupled with the imperfect market mechanism in China, has exacerbated local industrial wastewater discharge. The coefficient of environmental regulation (reg) in model 4 is positive and has passed the significance test, indicating that the higher the level of environmental regulation in the Central region, the more suppression there is on industrial wastewater discharge. The industry structure (industry) of models 2 and 6 both pass the significance test at the 1% level, and the coefficient values are negative, indicating that the increase in the proportion of the value added of the secondary industry will reduce the discharge of industrial wastewater in the Eastern and Western regions. This may be because the second industry structure has gradually changed from rough processing to refined processing, from polluting products to clean products. Foreign direct investment (fdi) will exacerbate the discharge of industrial wastewater in the Eastern and Central regions.

Table 6. FE regression results for industrial wastewater in the eastern, central, and western regions

Variable	Eastern		Central		Western	
	model1	model2	model3	model4	model5	model6
Open	16.20*** (5.44)	16.23* (1.83)	-160.92** (-3.23)	-170.66*** (-3.23)	-111.26*** (-4.35)	-93.14** (-2.95)
(Open)2	-7.59*** (-3.71)	-6.44** (-2.36)	1410.46* (2.39)	1267.21** (2.39)	166.99*** (3.43)	117.56 (1.81)
(Open)3			-4002.00* (-1.87)	-3158.61* (-1.87)		
Pop		5.68 (0.47)		3.16 (1.34)		-2.33 (-0.26)
Pgdp		-0.21 (-0.41)		-1.37 (-1.36)		0.56 (1.14)
Reg		-0.20 (-1.69)		0.18*** (3.40)		-0.04 (-1.25)
Market				14.38*** (3.49)		22.52 (1.36)
Industry		-56.38*** (-5.63)		0.97 (0.14)		-62.12*** (-4.38)
Fdi		10.60* (2.12)		12.70** (2.43)		6.25 (0.35)

(2) Regression estimation of industrial sulfur dioxide (pso2)

The table below shows the fixed-effect regression estimation results of the trade openness level and industrial sulfur dioxide emissions (pso2) in the Eastern, Central and Western regions. By observing the empirical results, it is found that the coefficients of the trade openness level (open) and the square term $(\mathrm{Open})^2$ for industrial sulfur dioxide emissions in the Eastern, Central and Western regions did not pass the significance test, indicating that the relationship between trade and industrial sulfur dioxide emissions is not significant. This may be due to the influence of multiple economic factors on industrial sulfur dioxide emissions. In some areas of China, the economy is mainly driven by traditional resource-intensive industries such as coal and steel, which undoubtedly exacerbates the emissions of industrial sulfur dioxide.

The coefficients of environmental regulation (reg) in models 2, 4, and 6 are all positive and have passed the significance test, indicating that the higher the level of environmental regulation in the Eastern, Central, and Western regions, the more suppression there is on industrial sulfur dioxide emissions. The coefficients of industry structure (industry) in models 2 and 4 are positive and pass the significance test at the 1% level, indicating that the increase in the proportion of the value added of the secondary industry has exacerbated the increase in industrial sulfur dioxide emissions in the Eastern and Central regions. The coefficient value of foreign direct investment (fdi) in model 4 is positive and passes the significance test at the 1% level, indicating that the introduction of foreign capital in the Central region will lead to an increase in industrial sulfur dioxide emissions.

Table 7. FE regression results for industrial sulfur dioxide in the eastern, central, and western regions

Variable	Eastern		Central		Western	
	model1	model2	model3	model4	model5	model6
Open	-4.18 (-0.48)	-2.48 (-0.45)	9.68 (0.16)	-43.96 (-0.97)	-34.32 (-1.44)	-21.68 (-0.73)
(Open)2	1.27 (0.62)	1.28 (0.81)	-77.77 (-0.30)	71.58 (0.38)	35.94 (0.65)	24.74 (0.34)
Pop		-8.45 (-0.94)		-10.55* (-1.88)		-7.84 (-0.78)
Pgdp		-0.24 (-0.63)		1.27 (1.03)		-3.31 (-1.76)
Reg		0.54*** (4.93)		0.38*** (2.81)		0.15* (2.07)
Market		6.93* (1.90)		-8.02 (-0.91)		65.77 (1.77)
Industry		56.06*** (6.08)		27.25*** (2.69)		3.48 (0.11)
Fdi		3.64 (1.01)		52.90*** (4.01)		-93.30 (-1.45)

(3) Regression estimation of industrial dust (psmoke)

The table below shows the fixed-effect regression estimation results of the trade openness level and industrial dust emissions(psmoke) in the Eastern, Central, and Western regions. Analyzing the empirical results, it is found that the coefficients of the trade openness level(open) and the square term$(\mathrm{Open})^2$ for industrial dust emissions in the Eastern and Western regions did not pass the significance test, indicating that the relationship between trade and industrial dust emissions is not significant in these regions. In model 3, the coefficients of trade openness level(open), the square term, and the cubic term$(\mathrm{Open})^3$ all pass the significance test, with values of negative, positive, and negative, respectively. Even after introducing control variables, the relationship between trade and industrial dust emissions in the Central region shows an inverted N-shaped relationship.

The marketization level(market) in models 2, 4, and 6 all pass the significance test, and the coefficient values are positive, indicating that the increase in marketization level in the Eastern, Central, and Western regions will contribute to an increase in industrial dust emissions. The coefficient of foreign direct investment(fdi) in model 4 passes the significance test at the 1% level, and the coefficient value is positive, indicating that the introduction of foreign direct investment in the Central region has exacerbated the emission of industrial dust. This may be due to the lower threshold for foreign investment in the Central region, which has led to high-pollution, high-energy-consuming industries being transferred to the Central region, exacerbating the emission of industrial dust.

Table 8. FE regression results for industrial smoke and dust in the eastern, central, and western regions

Variable	Eastern		Central		Western	
	model1	model2	model3	model4	model5	model6
Open	-0.17 (-0.03)	1.84 (0.41)	-268.64** (-2.67)	-263.37*** (-3.27)	-14.70 (-0.88)	-10.22 (-0.41)
(Open)2	-0.17 (-0.07)	-0.64 (-0.14)	2622.87*** (3.69)	1872.68** (2.93)	9.59 (0.23)	0.10 (0.00)
(Open)3			-7460.32*** (-4.09)	-4150.2** (-2.55)		
Pop		-3.37 (-0.64)		0.31 (0.07)		3.48 (0.52)
Pgdp		0.17 (0.46)		1.41 (1.33)		0.87 (0.69)
Reg		0.06 (0.36)		0.74** (2.60)		0.03* (1.93)
Market		15.36*** (5.54)		23.40* (2.22)		26.13* (2.01)
Industry		0.19 (0.04)		12.68 (0.85)		-20.40 (-0.94)
Fdi		-1.76 (-0.88)		68.37*** (4.46)		-51.72 (-1.50)

Based on the comprehensive analysis of the empirical results by region, the trade openness level in the Eastern region shows an inverted U-shaped relationship with industrial wastewater discharge; the trade openness level in the Central region shows an inverted N-shaped relationship with industrial wastewater discharge and industrial dust emissions; the trade openness level in the Western region shows a U-shaped relationship with industrial wastewater discharge. The higher the level of environmental regulation(reg), the lower the emissions of pollutants in the

Eastern, Central, and Western regions. The higher the level of marketization(market), the more exacerbated the emissions of pollutants in the Eastern, Central, and Western regions, indicating that China's market mechanism is imperfect and unable to improve energy efficiency. The industry structure(industry) can reduce the discharge of industrial wastewater in the Eastern and Western regions and exacerbate the emissions of industrial sulfur dioxide in the Eastern and Central regions, indicating that promoting industrial development in the Western region can reduce environmental pollution. Foreign direct investment(fdi) exacerbates industrial wastewater, sulfur dioxide, and dust emissions in the Central region, indicating that the introduction of foreign capital in the region verifies the "pollution haven hypothesis".

3.3. Intermediary model estimation results

According to existing scholars' research analysis, trade relations have enabled one country to obtain more opportunities for technology imitation and learning by importing products, equipment, and instruments from developed countries. At the same time, under the background of open and developed trade, the country will face more intense competition and have to increase research and development investment, undoubtedly playing a crucial role in improving the country's technological level. In order to explore the direct and indirect effects of trade openness on environmental pollution, this article introduces technological innovation (tech) as a mediator variable and conducts an empirical analysis of the mediating effect of trade openness on environmental pollution. Firstly, the intermediary model is introduced.

$$Y=aX+u_1 \tag{9}$$

$$Z=bX+u_2 \tag{10}$$

$$Y=cX+dZ+u_3 \tag{11}$$

In which Y is the dependent variable, Z is the mediator variable, and X is the explanatory variable. Firstly, the significance of coefficient a is verified by regression analysis of equation (9). If the significance test is passed, the intermediary model test can be conducted. Secondly, the corresponding regression estimates are performed on equations (10) and (11). If coefficients b and d pass the significance test, there is a mediating effect. If coefficient c also passes the significance test, it indicates that the explanatory variable X has a direct effect on the dependent variable Y. The empirical analysis equation established in this article is shown below:

$$Tech_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\beta_4 pgdp_{it}+\beta_5 reg_{it}+\beta_6 pop_{it}+\beta_7 market_{it}+\beta_8 industry_{it}+\beta_9 fdi_{it}+\mu_{it} \tag{12}$$

$$pollution_{it}=\beta_0+\beta_1 open_{it}+\beta_2 open_{it}^2+\beta_3 open_{it}^3+\beta_4 pgdp_{it}+\beta_5 reg_{it}+\beta_6 pop_{it}+\beta_7 market_{it}+\beta_8 industry_{it}+\beta_9 fdi_{it}+\beta_{10} Tech_{it}+\mu_{it} \tag{13}$$

The variable "pollution" refers to environmental pollution, including three indicators: industrial wastewater (pwater), industrial sulfur dioxide (pso2), and industrial smoke and dust (psmoke). The previous regression has completed the first part of the mediation effect test corresponding to Formula (9), demonstrating that the level of trade openness has an effect on environmental pollution. The second and third parts of the mediation effect test can be further conducted. Formula (12) corresponds to Equation (10), and Formula (13) corresponds to Equation (11). In order to ensure the robustness of the results, this study uses three estimation methods, namely FE, PCSE, and MLE, to perform regression estimation on Formulas (12) and (13), respectively.

(1) The indicator of environmental pollution is industrial wastewater discharge (pwater)

Table 9 presents the empirical estimates of the intrinsic causal mechanism between trade and industrial wastewater emissions. Analyzing the empirical results, in Model 1, the dependent variable is technical innovation (tech), where the trade openness level (open) along with its quadratic term $(\mathrm{Open})^2$ and cubic term $(\mathrm{Open})^3$ passed the significance test at the 1% level. Among them, the coefficient of the variable(open) is positive, the coefficient of the variable $(\mathrm{Open})^2$ is negative, and the coefficient of the variable$(\mathrm{Open})^3$ is positive. It is found that the influence of trade on technical innovation shows a nonlinear relationship that exhibits an "N-shaped" curve. Both Model PCSE and Model MLE obtained consistent conclusions. This indicates that the continuous improvement of the trade level will first promote the improvement of the technical innovation level, and then have some degree of inhibition. In the long run, it will promote the improvement of the technical innovation level. This may be because, in the initial stage of opening up to the outside world, China, with insufficient innovation capability, can lower enterprise costs and improve profit margins by importing advanced intermediate inputs from abroad, thus creating sufficient funds to support R&D investment and enhance its own innovation capabilities to achieve the spillover effect of technology. However, with the increase of trade level, due to the large gap in technology and relatively scarce talent resources between China and other foreign countries, China cannot fully absorb advanced technology, which leads to the occupation of the domestic market by foreign advanced products. In addition, China's export trade is still dominated by processing trade, which to some extent inhibits the country's technological innovation process. In the long run, the increase of trade level is conducive to the improvement of the level of technical innovation. In Model 2 and Model 6, the coefficient of technical innovation(tech) is negative and passed the significance test, indicating that trade plays an intermediary role in industrial wastewater emissions through technical innovation. Therefore, Hypothesis 2 is established at the level of the industrial wastewater emissions(pwater) index. The regression results of the model that introduces technical innovation as the explanatory variable and industrial wastewater emissions as the dependent variable show that the coefficient of trade openness level is basically significant, indicating that the direct effect of trade openness on industrial wastewater emissions also exists.

Table 9. Regression results of the mediation model between industrial wastewater discharge and trade openness level

Variable	model1 FE Tech	model2 FE Pwater	model3 PCSE Tech	model4 PCSE Pwater	model5 MLE Tech	model6 MLE Pwater
Tech		-0.49*** (-3.09)		-0.20 (-1.32)		-0.39*** (-2.65)
Open	12.08*** (3.44)	-38.76*** (-4.04)	10.00** (3.44)	22.63** (2.18)	14.75*** (4.51)	-31.76*** (-3.47)
(Open)2	-27.40*** (-5.98)	37.37*** (2.87)	-10.89** (-5.98)	-19.38 (-1.55)	-24.91*** (-5.78)	37.64*** (3.10)
(Open)3	10.62*** (6.05)	-12.38** (-2.48)	3.28* (6.05)	4.86 (1.08)	9.12*** (5.53)	-13.59*** (-2.95)
Pop	-1.64 (-0.92)	-2.323 (-0.48)	0.18 (-0.92)	-8.18*** (-2.97)	-1.20 (-0.74)	-3.73 (-0.85)
Pgdp	0.90*** (4.73)	-0.85 (-1.60)	0.73*** (4.73)	0.02 (0.05)	1.26*** (8.75)	-0.41 (-0.94)
Reg	0.03*** (3.35)	-0.005 (-0.18)	0.01 (3.35)	0.02 (1.31)	0.02*** (3.08)	-0.007 (-0.28)
Market	-3.23 (-1.51)	24.48*** (4.26)	2.65 (-1.51)	19.43*** (3.38)	-1.54 (-0.75)	26.53*** (4.87)
Industry	-0.19 (-0.07)	-24.79*** (-3.11)	2.01 (-0.07)	31.16*** (4.28)	-2.53 (-0.99)	-21.34*** (-2.95)
Fdi	-6.10*** (-3.97)	5.26 (1.24)	-2.48** (-3.97)	-4.85 (-1.22)	-5.88*** (-4.02)	5.37 (1.34)

(2) The environmental pollution indicator is industrial SO2 emissions (pso2)

Table 10 presents the empirical estimates of the intrinsic causal mechanism between trade openness level and industrial SO2 emissions. The influence of trade openness level on technical innovation shows a nonlinear relationship that exhibits an "N-shaped" curve, which is consistent with the analysis results of the industrial wastewater emissions indicator. The coefficient of technical innovation (tech) in Model 2 and Model 6 is positive but did not pass the significance test, while the coefficient of technical innovation (tech) in Model 4 is negative and passed the significance test at the 5% level. This indicates that the intermediary effect of trade through technical innovation (tech) on industrial SO2 emissions exists but is not robust. Therefore, the hypothesis 2 is established at the level of industrial SO2 emissions (pso2) index.

Table 10. Regression results of intermediate model between industrial sulfur dioxide emissions and trade openness level

Variable	model1 FE Tech	model2 FE Pso2	model3 PCSE Tech	model4 PCSE Pso2	model5 MLE Tech	model6 MLE Pso2
Tech		0.18 (1.07)		-0.52** (-2.47)		0.07 (0.43)
Open	12.08*** (3.44)	-27.48*** (-2.62)	10.00** (3.44)	-17.66 (-1.64)	14.75*** (4.51)	-27.50*** (-2.82)
(Open)2	-27.40*** (-5.98)	21.19 (1.49)	-10.89** (-5.98)	15.78 (1.37)	-24.91*** (-5.78)	23.06* (1.75)
(Open)3	10.62*** (6.05)	-5.40 (-0.99)	3.28* (6.05)	-4.61 (-1.26)	9.12*** (5.53)	-6.20 (-1.24)
Pop	-1.64 (-0.92)	4.83 (0.92)	0.18 (-0.92)	-7.20** (-2.17)	-1.20 (-0.74)	1.62 (0.34)
Pgdp	0.90*** (4.73)	-1.20** (-2.07)	0.73*** (4.73)	1.29** (2.05)	1.26*** (8.75)	-0.65 (-1.34)
Reg	0.03*** (3.35)	0.16*** (5.24)	0.01 (3.35)	0.32*** (3.69)	0.02*** (3.08)	0.17*** (6.16)
Market	-3.23 (-1.51)	28.73*** (4.57)	2.65 (-1.51)	11.15 (1.41)	-1.54 (-0.75)	24.53*** (4.09)
Industry	-0.19 (-0.07)	28.64*** (3.28)	2.01 (-0.07)	38.33*** (4.71)	-2.53 (-0.99)	30.02*** (3.96)
Fdi	-6.10*** (-3.97)	4.95 (1.07)	-2.48** (-3.97)	-3.037 (-0.90)	-5.88*** (-4.02)	3.99 (0.92)

(3) The environmental pollution indicator is industrial smoke and dust emissions (psmoke)

Table 11 presents the empirical estimates of the intrinsic causal mechanism between trade openness level and industrial smoke and dust emissions. The influence of trade openness level on technical innovation shows a nonlinear relationship that exhibits an "N-shaped" curve, which is consistent with the analysis results of the industrial wastewater emissions indicator. The coefficients of technical innovation (tech) in Models 2, 4, and 6 are negative, but only the coefficient in Model 4 passed the significance test at the 1% level. This indicates that the intermediary effect of trade through technical innovation (tech) on industrial smoke and dust emissions exists but is not robust. Therefore, the hypothesis 2 is established at the level of the industrial smoke and dust emissions (psmoke) index.

Table 11. Regression results of the mediating model between industrial smoke and dust emissions and trade openness level

Variable	model1 FE Tech	model2 FE Psmoke	model3 PCSE Tech	model4 PCSE Psmoke	model5 MLE Tech	model6 MLE Psmoke
Tech		-0.08		-0.39***		-0.20
		(-0.65)		(-2.80)		(-1.64)
Open	12.08***	-10.36	10.00**	-14.10	14.75***	-13.71*
	(3.44)	(-1.27)	(3.44)	(-1.62)	(4.51)	(-1.80)
(Open)2	-27.40***	10.46	-10.89**	7.05	-24.91***	7.85
	(-5.98)	(0.49)	(-5.98)	(0.72)	(-5.78)	(0.77)
(Open)3	10.62***	-3.62	3.28*	-1.47	9.12***	-2.10
	(6.05)	(-0.85)	(6.05)	(-0.45)	(5.53)	(-0.54)
Pop	-1.64	5.40	0.18	-4.67	-1.20	3.62
	(-0.92)	(1.32)	(-0.92)	(-1.57)	(-0.74)	(0.98)
Pgdp	0.90***	1.23*** (2.72)	0.73***	1.52*** (3.47)	1.26***	1.01***
	(4.73)		(4.73)		(8.75)	(2.81)
Reg	0.03***	0.03	0.01	0.13***	0.02***	0.05**
	(3.35)	(1.41)	(3.35)	(3.30)	(3.08)	(2.42)
Market	-3.23	10.01**	2.65	-2.83	-1.54	6.64
	(-1.51)	(2.04)	(-1.51)	(-0.40)	(-0.75)	(1.43)
Industry	-0.19	-0.80	2.01	21.13***	-2.53	7.360
	(-0.07)	(-0.12)	(-0.07)	(2.62)	(-0.99)	(1.22)
Fdi	-6.10***	-6.04*	-2.48**	-7.83**	-5.88***	-8.43**
	(-3.97)	(-1.68)	(-3.97)	(-2.41)	(-4.02)	(-2.47)

Through the analysis of the mediation model, the hypothesis 2 is basically validated. Specifically, for the industrial wastewater emissions (pwater) index, the trade openness level plays a partial mediating effect through technical innovation, that is, trade can directly affect industrial wastewater treatment and indirectly affect industrial wastewater treatment by influencing the level of technical innovation. As for the industrial SO2 (pso2) and smoke and dust (psmoke) emissions indicators, although the intermediary effect of trade openness on environmental pollution control exists, the results are not robust, indicating that the mechanism through which trade affects environmental pollution control is more complex. It not only directly affects environmental pollution control but also indirectly affects the governance of environmental pollution by influencing other economic variables.

4. Conclusion

Through the analysis presented in this paper, several conclusions have been drawn:

Firstly, the analysis of the benchmark model and the full sample regression indicates that the relationship between the trade openness level and industrial wastewater emissions exhibits an inverted "N" shape, while the relationship between trade openness and industrial SO2 emissions is "U" shaped, and trade openness has a negative linear relationship with industrial smoke and dust emissions. The impact of trade openness on environmental pollution control varies depending on the type of pollutant. However, in general, the increase in the trade openness level will contribute to solving environmental pollution problems.

Secondly, the empirical regression analysis by region shows that the trade openness level in China's eastern region exhibits an inverted "U" shaped relationship with industrial wastewater emissions, while in the central region, the trade openness level is negatively related to industrial wastewater emissions and industrial smoke and dust emissions in an inverted "N" shaped relationship. In the western region, the trade openness level exhibits a "U" shaped relationship with industrial wastewater emissions. Furthermore, in terms of the industrial wastewater emissions indicator, the industrial structure plays a supportive role in pollution control in the western region but acts as an obstacle in the central region. Specifically, a higher proportion of the industrial structure will reduce industrial wastewater emissions in the western region, indicating that promoting industrial development in this region can reduce environmental pollution.

Thirdly, there is still irrationality in foreign investment. Although foreign direct investment can reduce industrial smoke and dust emissions and pollutant emissions in China, it can worsen the emission of the three types of pollutants in the central region, indicating that the hypothesis of the "pollution haven" is valid in the central region.

Fourthly, higher levels of marketization exacerbate environmental pollution in the eastern, central, and western regions of China, indicating that the marketization mechanism in our country is not perfect and has not achieved the improvement of resource rationalization and utilization efficiency. Moreover, the higher the level of environmental regulation, the lower the pollution levels in these three regions.

Finally, the empirical analysis of the mediation model indicates that trade openness can play an intermediary effect on environmental pollution control through the intermediate variable of technical innovation. Specifically, hypothesis 2 is established at the level of industrial wastewater emissions. Although the intermediary effect of trade openness on environmental pollution control exists at the level of industrial SO2 and industrial smoke and dust emissions, the results are not robust.

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