Institute for Economic Forecasting

3. RESEARCH ON THE NON-LINEAR IMPACT OF CHINA'S PROVINCIAL IMPORT AND EXPORT TRADE ON CARBON EMISSIONS BASED ON THE PSTR MODEL

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Abstract

With the coming of the trend of global economic integration, the conflict between trade openness and environmental issues is increasingly intensifying. As a result of global warming and frequent smog, the government and the public are paying unprecedented attention to environmental prevention and governance. It has been particularly signifi-cant to coordinate the balance between trade and environment. Based on the provincial panel data of 30 provinces in China from 2004 to 2016, the non-linear impact of import and export trade on carbon emissions, considering the influence of economic develop-ment level on carbon emission effect of China's trade, is analyzed by using the panel smooth transition regression model (PSTR). The results show that the export trade and import trade have double threshold characteristics on carbon dioxide emissions with economic development level as the transfer variable. The positive promotion effect of export trade on China's carbon dioxide emissions decreases with the improvement of economic development level. The promotion effect of import trade volume on carbon di-oxide emissions shows a non-linear characteristic of first weakening and then slightly strengthening with the improvement of economic level.

Keywords: import and export trade; carbon emission; PSTR model

JEL Classification: F18, C23

1. Introduction

Since the 1980s, global environmental problems have become increasingly prominent, such as ozone depletion, greenhouse effect, land desertification and water pollution. The public has paid more and more attention to environmental quality. It is a one-sided and unsustainable economic development pattern to only pursue economic growth without

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considering environmental costs. Chinese economic and social development is facing multiple pressures concurrently from economic growth, trade expansion and en-vironmental pollution. The pressure from the environment and resources is increasing in the process of economic operation. China, due to the specialization and fine division of labor, is in the low-end position in the production chain and becomes the “world factory” in trade. Trade expansion, which has made great contributions to economic develop-ment, has caused a great quantity of energy consumption undoubtedly. A series of en-vironmental problems come one after another, among which the global warming caused by carbon dioxide emissions, has aroused widespread concern at home and abroad.

Following the United Nations Framework Convention on climate change and the Kyoto Protocol, the Paris Agreement has once again responded to global climate governance and made arrangements for global actions to deal with climate change after 2020. As the largest developing country and a contracting party to the international climate negotia-tions, shoulders great pressure and responsibility for carbon emission reduction, and promises to reach the peak of carbon dioxide emissions by 2030. With the strengthening of environmental resource constraints, the Chinese economy is in an important strategic opportunity period for structural adjustment, and commits to the green, low-carbon, sus-tainable development policy. The 13th Five-Year Plan outlines the response to climate change as one of the main contents of green development, and puts forward a phased goal, that is, carbon dioxide emissions per unit of GDP decreased by 18% annually. The report of the 19th National Congress of the Communist Party of China once again stressed the need to speed up the reform of the ecological civilization system and "estab-lish and improve the economic system of green, low-carbon and circular development".

Academic circles have different standpoints on the relationship between import and ex-port trade and environmental issues of the developing countries. Walter and Ugelow’s (1979) Pollution Paradise Hypothesis holds that developed countries tend to transfer pollution-intensive industries to developing countries through overseas trade, thus ag-gravating the environmental pollution in developing countries. Then, Antweiler et al. (2001) questioned the above viewpoints, established an environmental three-effects model (ACT) by introducing the environmental factors into the general equilibrium theory and conducted an empirical test based on the sulfur dioxide data of many countries. Eventually, they concluded that freer trade is beneficial to the environment. Stretesky and Lynch (2009) used fixed effect regression to study the relationship between per cap-ita carbon dioxide emissions and exports trade based on the panel data of 169 countries from 1989 to 2003, and ultimately found that there was a positive correlation between them. Ang (2009) collected the time sample data of China from 1953 to 2006 for more than half a century to explore the decisive factors of China's carbon dioxide emissions. The results show that more energy use, higher income and greater trade openness tend to cause more carbon dioxide emissions. Domestic scholars believe that foreign trade has a two-way effect on domestic environment. Zhang et al. (2003) selected cross-sectional data of 31 provinces in China in 2000 for regression, the results show that the scale effect of trade increases pollution, while technology effect and composition effect reduce pollution, and the total effect of trade on environmental protection is posi-tive, that is, trade openness is conducive to the improvement of domestic environment. Zhuang et al. (2009) choose the data on China from 1981 to 2006 for econometric re-gression, and found that the environmental effects of China's trade can improve the en-vironment. Some scholars hold the opposite attitude. Chen and Xu (2010), Shen and Tang (2008) thought that the speed of technological progress promoted by trade cannot keep up with the growth rate of huge trade surplus, so the total pollution emissions of export products are still rising. Based on the panel data of 29 provinces and municipalities in China, Tang and Zhou (2017) empirically tested the negative effect of Chinese foreign trade on the environment, and the foreign trade system needs further reform.

At present, most scholars use the conventional linear analysis framework to study the impact of trade on environmental pollution. It is difficult to fully and reasonably consider the role of economic development level in the process of trade affecting environmental pollution, and to explain the impact of import and export trade on environmental pollution may be different in different stages of economic development. The Environmental Kuz-nets Curve proposed by Grossman and Krueger (1995) points out that when a country's economic development level is low, environmental pollution will increase with economic growth; however, when the economic level reaches a certain level, with the increase in per capita income, its environmental pollution will slow down with the economic devel-opment. As a part of social and economic activities, the impact of trade liberalization on the environment is also twofold: on the one hand, the expansion of trade has accelerat-ed the consumption of energy, thus aggravating the problem of environmental pollution in the developing countries. On the other hand, the rapid development of trade has brought about the improvement of the economic level of various countries, which has higher requirements on the living environment, and also has more ability and technology to improve the ecological environment. Considering the above two aspects comprehen-sively, this paper intends to analyze how the impact of import and export trade on envi-ronmental pollution can be smoothly transferred between different systems under the influence of different economic levels from the perspective of non-linearity. In addition, combined with the domestic and international background of low-carbon emission re-duction, this paper selects the carbon dioxide emission as an indicator to reflect envi-ronmental pollution.

2. Materials and Methods

2.1. Theoretical Framework

Based on the research and analysis ideas of Antweiler *et al.* (2001), this paper establishes a general equilibrium model to describe the impact of trade on the environment. Suppose that in a small open economy, there are mainly two kinds of products, named X and Y, where X is a capital-intensive product, and pollutant Z will be emitted in the production process; Y is a labor-intensive product, and no pollutant will be produced in the production process. The main factors of production consumed in production process are capital K and labor L, and the marginal returns of the two factors of production are interest rate r and wage w, respectively. The production function returns to scale are constant, and the production cost functions of X and Y are expressed by $C^X(w,r)$ and $C^Y(w,r)$, respectively. In addition, referring to the practice of Tang and Zhou (2017), we take the price of Y as the benchmark price, that is $P_y = 1$, the price of X is P_x.

There are some factors, such as resource endowment, geographical location and trade barriers, which lead to different prices of the same product in the international market and the domestic market. Assuming that the coefficient of trade friction is β and the international market price of X is P_x^w, then there are:

$$\beta = \frac{P_x}{P_x^w} \tag{1}$$

If the domestic price of X is higher than the international price, then X is imported, if not, X is exported. Under pressure from government on environmental regulation, production enterprises have to take a part of production resources to control environmental pollution when X is produced.

Assuming that the proportion of production resources used by enterprises for environmental governance is θ, the size of θ will affect the output of X, as follows:

$$x = (1-\theta) F(K_x, L_x) \tag{2}$$

$$z = e(\theta) x \tag{3}$$

where: $e(\theta)$ is the pollution emission function for unit output of X. In addition, the government imposes a pollution tax of τ to limit the emission of pollution. Then the producer's profit is equal to the total revenue minus the input cost of production factors, the cost of pollution control and pollution tax, as follows:

$$\pi = P_x x - K_x r - L_x w - \theta P_x x - \tau z \tag{4}$$

Let $P_n = (1-\theta) P_x - e(\theta)\tau$, which means the net production price of the X, then the above profit function can be expressed as:

$$\pi = P_n x - K_x r - L_x w \tag{5}$$

According to the equilibrium condition of maximizing the profit of the producer, calculating the first-order derivation of Eq. (5), and let

$$\frac{\partial \pi}{\partial \theta} = -P_x - \tau e'(\theta) = 0 \tag{6}$$

From the calculation above, we get:

$$P_x = -\tau e'(\theta) \tag{7}$$

From this, it can be found that θ is a function of τ / P_x and $e(\theta)$ can be expressed as $e(\tau / P_x)$, where $e' < 0$. The equilibrium is reached when the producer earns zero profits under the condition of perfect competition market, then:

$$\begin{cases} P_n = C^X(w, r) \\ 1 = C^Y(w, r) \\ L = C_w^X x + C_w^Y y \\ K = C_r^X x + C_r^Y y \end{cases} \tag{8}$$

With reference to the practices of Zhang *et al.* (2003) and Chen and Xu (2010), assuming that the total number of people in this open economy is N, these individuals are divided into consumers of green behavior (N^g) who are more concerned about the environment and consumers of brown behavior (N^b) who are less concerned about the environment, according to different consumers' preferences for environmental pollution (*i.e.*, level of tolerance). Since different types of consumers have different preferences for environmental pollution, it is assumed that the same environmental pollution has different effects on different types of consumers, and in the case of a certain pollution level, the utility function of consumers is as follows:

$$V^i\left(p_x, I, z\right) = u\left(I\right) - \delta^i z \tag{9}$$

where: $i = \left(g, b\right)$, δ^i is pollution emission, Z is the marginal loss of consumers, and $\delta^g > \delta^b \geq 0$; I is the actual income of consumers, u is the total utility of consumers using their own income to buy products.

The government takes the measure of collecting pollution tax on pollution emissions, which can maximize the welfare of the whole economy. The welfare function of the economy as a whole is obtained by weighted summation of the utility functions of each consumers, as follows:

$$\max_{\tau} N\left(\lambda V^g + \left(1\text{-}\lambda\right)V^b\right) \tag{10}$$

where: λ means the government's attention for consumers of green behavior, and the larger λ means a higher attention of government for consumers of green behavior and more stringent policies will be made to prevent environmental pollution. Its first-order conditions is

$$u^{'}\left(I\right)\frac{dI}{d\tau} - [\lambda\delta^g + (1-\lambda)\delta^b]\frac{dz}{d\tau} = 0 \tag{11}$$

The total revenue G of an economy is made up of two components, which contain total revenue of private sectors and taxes, where $R = R\left(P_n, K, L\right)$ means total revenue of private sectors, then $G = R\left(P_n, K, L\right) + \tau z$ .Consumer real revenue equals total revenue divided by total number of people and divided by price index, that is, $I = \frac{G/N}{\sigma\left(P_x\right)}$. Calculate the first derivative of taxes τ when the world price is fixed.

$$\frac{dI}{d\tau} = \frac{1}{N\sigma\left(P_x\right)}\left[R^{'}\left(P_n, K, L\right)\frac{dP_n}{d\tau} + z + \tau\frac{dz}{d\tau}\right] = \frac{\tau}{N\sigma\left(P_x\right)}\frac{dz}{d\tau} \tag{12}$$

Put Eq. (12) into Eq. (11) to get:

$$\tau = \frac{N\sigma\left(P_x\right)}{u^{'}\left(I\right)}[\lambda\delta^g + (1-\lambda)\delta^b] = N\left[\lambda MD^g\left(P_x, I\right) + (1-\lambda)MD^b(P_x, I)\right] \tag{13}$$

where: $MD^i = \delta^i\sigma\left(P_x\right)/u^{'}$ represents the marginal damage of different types of consumers, and Eq. (13) indicates that the pollution tax is equal to the sum of the per capita marginal losses of all consumers. Let $T = \lambda N\delta^g + (1-\lambda)N\delta^b$ denote the type of country, which is mainly used to measure the government's attention to the environment. Given $\phi(P_x, I) = \frac{\sigma(P_x)}{u^{'}}$, then Eq. (13) can be written as follows:

$$\tau = \mathrm{T}\phi(P_x, I) \tag{14}$$

It can be seen from the above formula that the emission of pollution eventually makes the pollution tax equal to the total weighted marginal damage of consumers, and the choice of pollution control policy is affected by the type of country, product price and real per capita income.

According to Eq. (1) and Eq. (14), the supply curve of pollution emission can be obtained:

$$\hat{\tau} = \hat{T} + \varepsilon_{MD,P_x}\hat{\beta} + \varepsilon_{MD,P_x}\hat{P}_x^w + \varepsilon_{MD,I}\hat{I} \tag{15}$$

where: ^ represents the rate of change of variables. Eq. (15) reflects that the changes of country type, trade friction, international market price and consumers' real income will cause the changes of pollution supply. The change of a country's attention to environmental protection will lead to the change in the type of country. If the proportion of green behavior consumers increases in a country, then the country's environmental requirements will also be relatively higher and will reduce the country's pollution supply.

According to Eq. (3), the emission of environmental pollutants is determined by the output of X and pollutant emission per unit product, which is the demand of enterprises for pollution emission. For the convenience of research, let S denote the economic scale, that is $S = P_n x + y$, $\varphi = (x/y)/[P_n \cdot (x/y) + 1]$ indicates the importance of polluting industry (i.e. product X) in the whole economy, according to Eq. (8), we know that $x/y = (C_w^Y k - C_r^Y)/(C_r^X - C_w^Y k)$, $(k = K/L)$,that is, φ is a function of P_n and k; then Eq. (3) can be expressed in the following form:

$$z = e(\theta)\varphi(P_n, k)S \tag{16}$$

According to this, the total differentiation of Eq. (16) leads to Eq. (17). As shown in Eq. (17), the change of pollution emission is affected by pollution emission intensity, industrial structure and economic scale.

$$\hat{z} = \hat{e} + \hat{\varphi} + \hat{S} \tag{17}$$

The total differentiation of e and φ is carried out, and their results are brought into Eq. (17) to further analyze the impact factors needed for pollution emission:

$$\begin{aligned}\hat{z} = \hat{S} + \varepsilon_{\varphi,k}\hat{k} + \left[\varepsilon_{e,P_x/t} + (1+c)\varepsilon_{\varphi,P_x}\right]\hat{\beta} + \left[\varepsilon_{e,P_x/t} + (1+c)\varepsilon_{\varphi,P_x}\right]\hat{P}_x^w \\ -[c\varepsilon_{\varphi,P_x} + \varepsilon_{e,P_x/t}]\hat{\tau}\end{aligned} \tag{18}$$

According to Eq. (15), it may be seen that economic factors such as the degree of national attention to environmental pollution, price and income will affect the supply of environmental pollutants. According to Eq. (18), one may see that the changes of economic scale, capital labor ratio and international market price will affect the demand for pollution emissions.

Considering Eq. (15) and Eq. (18), we can get the emission of environmental pollution in general equilibrium, as follows:

$$\hat{z} = \pi_1\hat{S} + \pi_2\hat{k} + \pi_3\hat{\beta} + \pi_4\hat{P}_x^w - \pi_5\hat{I} - \pi_6\hat{T} \quad (19)$$

In Eq. (19), π_i is the influence coefficient of various economic factors on environmental pollution. It shows that the change of environmental pollution depends on many factors, such as economic scale, capital labor ratio, trade barriers, international market prices, real per capita income and changes of country type. It quantifies the scale effect, structure effect and technology effect of the impact of trade on the environment.

2.2. Empirical Design

2.2.1. Data and Variable Description

According to the analysis of the above general equilibrium model, import and export trade have different effects on environmental pollution mainly through the scale effect, structure effect and technology effect. The indicators reflecting environmental pollution generally include carbon dioxide (Ang, 2009) and sulfur dioxide (Antweiler *et al.*, 2001). Considering the background of low-carbon emission reduction in this paper, the more representative carbon dioxide emissions are selected as the explained variables. Therefore, we select carbon dioxide emissions as the dependent variable, export trade and import trade as the indicators to measure the scale effect, GDP per capita as the indicator to measure the level of economic development; capital labor ratio (*i.e.,* capital abundance) as an indicator of structural effect. As the world price is difficult to consider, it is excluded from the model. In addition, considering that the introduction of foreign capital will improve domestic production technology to a certain extent, the dependence on foreign capital is taken as a variable to measure the level of technology.

Based on the Environmental Kuznets Curve proposed by Panayotou (1993), we realize that with the increase in income level, environmental pollution will increase first and then decrease. Therefore, this paper selects GDP per capita as a threshold variable to reflect the level of regional economic development, so as to further analyze the different effects of import and export trade on environmental pollution under different levels of economic development. The original data are retrieved from China Statistical Yearbook, China Economic and Social Development Statistics Database and World Bank Database, which covers 13 years of sample data in 30 provinces in China from 2004 to 2016.

(1) Dependent Variable

Carbon dioxide (CO_2) emission is selected as a proxy variable to measure environmental pollution. According to the method provided by IPCC (2006) national greenhouse gas emission inventory, carbon dioxide emissions are estimated based on energy consumption. The specific estimation methods are as follows:

$$CO_2 = \sum_{i=1}^{n} E_i \times V_i \times F_i \times O_i \times (44/12) \quad (20)$$

where: CO_2 is the total amount of carbon dioxide emission; E_i is the total energy consumption of class I; V_i is the Low Calorific Value; F_i is the carbon emission factor; O_i is the carbon oxidation factor; 44/12 is the molecular weight ratio of carbon dioxide to carbon; n is the total energy consumption category, which includes raw coal, coke, fuel oil, gasoline, kerosene, diesel and natural gas(China Statistical Yearbook divides energy consumption into nine categories, including raw coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel oil, natural gas and electric power. Because, in the terminal energy consumption, electricity consumption does not directly produce carbon dioxide, which belongs to secondary energy. Therefore, this paper does not include electricity consumption in the estimation process. In addition, due to the lack of crude oil data, this paper does not use electricity consumption). Among the above variables, the missing energy consumption data of some provinces are filled by interpolation. The energy consumption data of provinces are mainly from China Statistical Yearbook, and the low calorific value, carbon emission factor and carbon oxidation factor of energy refer to IPCC (2006).

(2) Explanatory Variables Describing the Scale of Trade

It mainly includes two trade indicators: export trade volume (EXP) and import trade volume (IMP), which are obtained by using the real effective exchange rate index to deflate the total exports and imports respectively (100 million yuan), respectively. The original import and export data are from China Statistical Yearbook, and the real effective exchange rate index is from the World Bank Database.

(3) Threshold Variable

GDP per capita (GPC) is often used to measure the development level of a region and its nominal data comes from the National Bureau of Statistics.

In this paper, the real GDP per capita is set as the threshold variable, which is obtained by using GDP per capita index (base period 2003 = 100) to deflate the nominal GDP per capita (yuan per person). After taking logarithm of threshold variables, they are included in PSTR model as one of explanatory variables.

(4) Capital-labor Ratio

This paper measures the trade structure by the ratio of capital stock to employees in each province. The capital stock is calculated by perpetual inventory method.

$$K_{it} = I_{it} + (1-\mu)K_{i,t-1} \tag{21}$$

where: K_{it} represents the capital stock at the end of period t; $K_{it\text{-}1}$ represents the capital stock at the end of the previous period; I_{it} represents the actual investment in fixed assets in period t. and this paper uses the fixed asset investment index to convert the nominal value of fixed asset investment into the actual value; μ is the depreciation rate of capital and referring to Zhang *et al.* (2004)'s estimation of the economic depreciation rate of fixed capital in each province, this paper set as 9.6%.

In addition, referring to Xiang (2011)'s method of calculating initial capital stock, the capital stock of each province in 2004 is calculated, and then the capital stock of each province in each year is obtained. The fixed assets investment and fixed assets investment index are from China statistical annual inspection, and the number of employees is from China economic data network. In addition, referring to Xiang (2011)'s method of calculating initial capital stock, the capital stock of each province in 2004 is calculated, and then the capital stock of each province in each year is obtained. The amount of investment in fixed assets and the index of investment in fixed assets are taken from China Statistical Yearbook, and the number of employees is from China Economic Data Network.

(5) Dependence on Foreign Investment (f)

The opening of trade introduces foreign investment in China and improves the quality of labor force to a certain extent. In particular, the introduction of technology and science and technology by foreign investors can improve the level of domestic production technology and reduce the emission of environmental pollution. This paper uses the ratio of foreign direct investment to GDP to measure the degree of dependence on foreign investment. The original data comes from China Economic Data Network. Stata software was used for descriptive statistics of the above-mentioned variables, and the descriptive statistics of the variables are shown in Table 1.

Table 1. Descriptive Statistics of the Main Variables

Variable	Unit	N	Mean	Std.	Min	Max
co_2	ten thousand tons	390	29639.29	22044.12	1153.207	109697.5
exp	billion yuan	390	3276.143	6184.134	15.97034	40424.71
imp	billion yuan	390	2734.998	4892.161	7.281668	24476.81
gpc	yuan per person	390	15324.18	9808.325	3889.189	52647.8
k	ten thousand yuan per person	390	14.2079	10.0067	1.3635	1.3635
f	%	390	2.3802	1.8601	0.0386	8.0779

2.2.2. Data and Variable Description

This paper mainly studies the non-linear impact of import and export trade on carbon emissions. Taking GDP per capita as the threshold variable, this paper tests and estimates the explanatory variables affected by the threshold variable in turn. The final test model takes logarithm of some variables to measure the degree of change of the dependent variable when the explanatory variable changes by 1%.

Firstly, we build a two-mechanism panel smooth transition regression model (model 1) as follows:

$$lco_{2it} = \mu_i + \beta_{01} lexp_{it} + \beta_{02} lgpc_{it} + \beta_{03} lk_{it} + \beta_{04} f_{it} + (\beta_{11} lexp_{it} + \beta_{12} lgpc_{it} + \beta_{13} lk_{it} + \beta_{14} f_{it}) g(gpc_{it}; \gamma, c) + \varepsilon_{it} \tag{22}$$

where: lco_{2it} is the dependent variable, which is the carbon dioxide emissions of the i region in the t year expressed in logarithmic form; $lexp_{it}$, $lgpc_{it}$ and lk_{it} are the explanatory variables influenced by threshold variables, which are the total export trade, real GDP per capita and capital labor ratio expressed in logarithmic form; f_{it} is also an explanatory variable influenced by the threshold variable, which represents dependence of foreign investment. Since its unit is %, it is no longer logarithmic. In addition, $\varepsilon_{it}: \mathrm{iid}(0, \sigma^2)$.

$g(gpc_{it}; \gamma, c)$ is the conversion function, which is a bounded continuous function of gpc_{it} with a value between 0 and 1, which satisfies the form of logistic function:

$$g(q_{it}; \gamma, c) = \left\{1 + exp\left[-\gamma \prod_{j=1}^{m} \left(q_{it} - c_j\right)\right]\right\}^{-1} \tag{23}$$

where: is gpc_{it} is the threshold variable, which represents the real GDP per capita. γ is a smoothing parameter, which determines the conversion speed of the transfer function from one system to another near the threshold value. The larger the value, the greater the conversion speed between different systems. c is the position parameter of the transfer function. m represents the number of position parameters in the conversion function.

According to test results, which is non-residual and non-linear, this paper attempts to establish a multi-system panel smooth transition regression model as follows:

$$lco_{2it} = \mu_i + \beta_{01}lexp_{it} + \beta_{02}lgpc_{it} + \beta_{03}lk_{it} + \beta_{04}f_{it} + \sum_{j=1}^{r}(\beta_{11}lexp_{it} + \beta_{12}lgpc_{it} + + \beta_{13}lk_{it} + f_{it})g(gpc_{it};\gamma,c) + \varepsilon_{it} \quad (24)$$

The parameters in Eq. (24) have the same meaning as Eq. (22).

Accordingly, we can also build a two-system or multi- system panel smooth transfer regression model of import trade on carbon dioxide emissions based on GDP per capita (model 2):

$$lco_{2it} = \mu_i + \beta_{01}limp_{it} + \beta_{02}lgpc_{it} + \beta_{03}lk_{it} + \beta_{04}f_{it} + (\beta_{11}limp_{it} + \beta_{12}lgpc_{it} + \beta_{13}lk_{it} + + \beta_{14}f_{it})g(gpc_{it};\gamma,c) + \varepsilon_{it} \quad (25)$$

$$lco_{2it} = \mu_i + \beta_{01}limp_{it} + \beta_{02}lgpc_{it} + \beta_{03}lk_{it} + \beta_{04}f_{it} + \sum_{j=1}^{r}(\beta_{11}limp_{it} + \beta_{12}lgpc_{it} + + \beta_{13}lk_{it} + \beta_{14}f_{it})g(gpc_{it};\gamma,c) + \varepsilon_{it} \quad (26)$$

where: $limp_{it}$ is the explanatory variable affected by the threshold variable, which represents total export-import volume of the i region in the t year in logarithmic form, and the meaning of other variables is the same as Eq. (22).

3. Results Analysis

3.1. Model Checking

3.1.1. Stationary Test and Cointegration Test

In order to prevent the occurrence of spurious regressions, before the parameter estimation of the empirical model, the unit root test is carried out on the variable sequence in each panel model.

In this paper, LLC, IPS and Fisher-ADF are selected to test the stationarity of panel sequence, and the test results are shown in Table 2. Through the analysis of the above three test results, we get the following conclusions: the logarithm of total import value has passed the unit root test at the significance level of 1%. In addition, other original sequences have not passed the unit root test, that is, these data are not stable and have unit root. However, the unit root test is carried out again after the first-order difference of all variables, it is found that all variables can reject the original hypothesis at the significance level of 1%, in other words, variables are stable after the first-order difference.

Table 2. Statistical Table of Unit Root Test Results of Panel Data

	Original sequence			First-order difference		
	LLC	IPS	Fisher	LLC	IPS	Fisher
lnc	-2.556*** (0.0053)	-4.674*** (0.0000)	-0.663 (0.7463)	-9.772*** (0.0000)	-7.494*** (0.0000)	3.166*** (0.0008)
lexp	-2.729*** (0.0032)	-2.780*** (0.0027)	-0.382 (0.6489)	-5.802*** (0.0000)	-5.518*** (0.0000)	6.4741*** (0.0000)
limp	-5.105*** (0.0000)	-2.880*** (0.0020)	16.861*** (0.0000)	-8.923*** (0.0000)	-7.320*** (0.0000)	30.249*** (0.0000)
lgpc	-1.482* (0.0692)	1.1986 (0.8847)	0.435 (0.3318)	-13.829*** (0.0000)	-7.028*** (0.0000)	3.6581*** (0.0001)
lk	-4.920*** (0.0000)	-0.0164 (0.4935)	1.118 (0.8682)	-7.650*** (0.0000)	-6.972*** (0.0000)	3.061*** (0.0011)
f	-5.578*** (0.0000)	-0.0239 (0.4905)	1.375 (0.9154)	-10.497*** (0.0000)	-7.501*** (0.0000)	21.198*** (0.0000)

*Note: ***, **, and * are significant at 1%, 5%, and 10% confidence levels respectively; () is the P value corresponding to each test statistic.*

In order to test whether there is a long-term equilibrium relationship between variables with unit root, this paper uses Kao and Pedroni test to carry out panel cointegration test. The original hypothesis of the test is that there is no cointegration relationship between variables. The above unit root test results show that the variable sequence is integrated of order 1, which can be used for cointegration test. The test results (Table 3) show that the variables in the export trade model (model 1) and import trade model (model 2) have cointegration relationship, that is, there is a long-term equilibrium relationship between the variables.

Table 3. Statistical Table of Panel Cointegration Test Results

	Kao		Pedroni	
	DF	ADF	PP	ADF
Model 1	2.7531*** (-0.0030)	2.0432** (-0.0205)	-5.4638*** (0.0000)	-4.2982*** (-0.0066)
Model 2	2.8019*** (-0.0025)	2.0354** (-0.0209)	-3.0856*** (-0.0010)	-2.0312** (-0.0211)

*Note: ***, **, and * are significant at 1%, 5%, and 10% confidence levels respectively; () is the P value corresponding to each test statistic.*

3.1.2. Fixed Effect Test

Before using panel data for PSTR, it is necessary to confirm whether it meets the conditions of fixed effect regression model, so F-test and Hausman-test are used to select the model. The final test results (Table 4) show that both F-test and Hausman-test can reject the original hypothesis at the level of 5% significance; that is, the fixed effect model is more suitable than the mixed regression model and random effect model, so the fixed effect model is finally selected.

Table 4. Panel Data Model Selection Test Results

Model checking	F-test		Hausman-test	
	F	P	χ^2	P
Model 1	486.02	0.0000	11.49	0.0216
Model 1	419.46	0.0000	28.19	0.0000

3.1.3. PSTR Model Test

Before the parameter estimation of PSTR model, the non-linear test and residual non-linear test are considered. If the test results reject the original linear hypothesis $H_0 : \gamma = 0$, the model is considered to have non-linear characteristics, and then the residual non-linear test is continued to determine the number of optimal transfer functions. The test results are shown in Table 5. According to the test results, LM, LMF and LRT statistics of all models reject the original hypothesis at the significance level of 1%, which indicates that the two models have significant non-linear characteristics, and also proves the correctness of using PSTR model as the empirical method. Then, according to the residual non-linear test results of the model, it can be seen that, both models reject the original hypothesis of $\gamma = 1$ at the significance level of 1%, and cannot reject the original hypothesis of $\gamma = 2$ at the significance level of 10%. Therefore, the number of optimal transfer functions of the two models is 2.

Table 5. Statistical Table of Non-linear Test and Residual Non-linear Test Results

Type of test	Test statistic	Model 1	Model 2
Non-linear test: $H_0 : \gamma = 0$ $H_1 : \gamma = 1$	LM	32.787*** (0.000)	53.370*** (0.000)
	LMF	8.169*** (0.000)	14.110*** (0.000)
	LRT	34.248*** (0.000)	57.393*** (0.000)
Residual non-linear test: $H_0 : \gamma = 1$ $H_1 : \gamma = 2$	LM	23.181*** (0.000)	33.816*** (0.000)
	LMF	5.498*** (0.000)	8.260*** (0.000)
	LRT	23.898*** (0.000)	35.373*** (0.000)
Residual non-linear test: $H_0 : \gamma = 2$ $H_1 : \gamma = 3$	LM	3.306 (0.508)	7.834* (0.098)
	LMF	0.735 (0.568)	1.763 (0.136)
	LRT	3.320 (0.506)	7.913* (0.095)

*Note: ***, **, and * are significant at 1%, 5%, and 10% confidence levels respectively; () is the P value corresponding to each test statistic.*

After determining the number of transfer functions of each model, it is necessary to determine the number of position parameters in each transfer function. This paper selects the optimal number of position parameters according to AIC and BIC minimum criteria and whether the position parameters are in a reasonable interval.

The results are shown in Table 6. According to the test results, although the AIC and BIC of model 1 are lower than other models when m = 2, the position parameter of model 1 exceeds its reasonable range. Therefore, this paper selects a position parameter for subsequent regression; the test results of model 2 show that the AIC and BIC are minimum when m = 1. According to the above results, the number of optimal position parameters of the two models is 1.

Table 6. The Choice of the Number of Optimal Position Parameters

m	Index	Model 1	Model 2
m=1	AIC	-1.288	-1.040
	BIC	-1.125	-0.877
	Out c Yes or NO	NO	NO
m=2	AIC	-1.363	-1.028
	BIC	-1.180	-0.845
	Out c Yes or NO	YES	NO
Conclusion		m=1	m=1

3.2. Analysis of Model Results

Based on the above test results, after selecting the optimal parameters of the model, this paper uses MATLAB to estimate the parameters of PSTR model. Referring to the research results of González *et al.* (2005), the initial values of parameters γ and c are obtained by using grid search, which are brought into the model to calculate the estimated values of coefficients, and then NLS is used to estimate the model. The goal is to minimize the sum of squares of residuals, and the optimal parameter estimation is obtained by iteration until the parameter convergence. The estimated results are shown in Table 7. This paper takes GDP per capita as the threshold variable. The larger the position parameter in the transfer function, the better the level of economic development.

For model 1, the non-linear regression model of export trade on carbon dioxide emissions, based on the change of GDP per capita, export trade on carbon dioxide emissions has double-threshold characteristics, and each characteristic function corresponds to a new system. When the per capita GDP is less than 9156 yuan, the export trade has a significant positive effect on carbon dioxide emissions ($\beta_0 = 0.7250 > 0$), every 1% increase in export trade will promote the increase in carbon dioxide emissions by 0.7250%. When the per capita GDP reaches the first threshold point (9156), the impact of export trade on carbon dioxide emissions smoothly shifts from 0.7250 to 0.6173 (0.7250-0.2154 / 2). At this moment, the positive effect of export trade on carbon dioxide emissions gradually weakens. When the per capita GDP exceeds the first threshold point, the impact of export trade on carbon dioxide emissions will continue to smoothly shift from 0.6173 to 0.5096 (0.7250-0.2154); subsequently, when the per capita GDP reached the second threshold (13007), the positive effect of export trade on carbon dioxide emissions continued to slow down, and the impact coefficient smoothly shifted to 0.4419 (0.7250-0.2154-0.1354 / 2), until the per capita GDP exceeded the second threshold and gradually stabilized at 0.3742 (0.7250-0.2154-0.1354). From the empirical results, one may see that the non-linear effect of export trade on carbon dioxide emissions is mainly stable in three systems. According to the level of GDP per capita from low to high, the impact coefficients of the three stable systems are 0.7250, 0.5096 and 0.3742, respectively, which shows that export trade has different degrees of promoting effect on carbon dioxide emissions of China, and the promoting effect will slow down with the improvement of economic development level. Therefore, it can be proved that economic development will indeed affect the environmental effects of export trade.

According to the empirical results, taking 2016 as an example, the regions (Guizhou, Yunnan, Gansu) in the low system (the GDP per capita of low system regions is less than 9156) are the western regions of China, and the scale of regional export trade in this province has the strongest promotion effect on carbon dioxide emissions. Relatively speaking, except for Hainan, GDP per capita of eastern China is higher than 13007, which is in the high system range, and the impact coefficient of export trade scale on carbon dioxide emissions is small. In economically developed areas, the public has higher requirements for environmental quality and pays attention to the use of low-carbon products. At the same time, foreign trade activities promote the economic development and improve the low-carbon technology of some provinces, which weakens the promotion effect of export trade on carbon emissions. From this point of view, the impact of export trade on carbon emissions varies in different regions due to different levels of economic development; therefore, different regions should implement different trade policies according to their own development and environmental status.

For model 2 (the non-linear regression model of import trade on carbon dioxide emissions), the impact of import trade on carbon dioxide emissions also has double threshold characteristics, which is based on the change in GDP per capita. When the per capita GDP is less than 9287, the import trade has a significant role in promoting carbon dioxide emissions ($\beta_0 = 0.4501 > 0$); When GDP per capita reaches the first threshold point (9287), the promoting effect of import trade on carbon dioxide gradually weakens, and the influence coefficient is smoothly transferred to 0.3424 (0.4501-0.2154/2), and finally it completely exceeds the first threshold point and stabilizes at 0.2347 (0.4501-0.2154). As GDP per capita continues to rise to the second threshold (13069), the promotion effect of import trade on carbon dioxide emissions is slightly strengthened, and the impact coefficient is 0.2666 (0.4501-0.2154+0.0638/2). Finally, after the per capita GDP exceeded 13069, the impact coefficient of import trade on carbon dioxide emissions gradually stabilized at 0.2958. It is worth noticing that the third system impact coefficient of import trade on carbon dioxide emissions is not significant. The impact of import trade on carbon dioxide emissions is mainly stable in the first two systems, and the corresponding impact coefficients are 0.4501 and 0.234, respectively.

This result can only show that before GDP per capita exceeds the second threshold, import trade has a significant promoting effect on domestic carbon dioxide emissions, but the promoting effect weakens with the improvement of economic level. According to the analysis of Mei and Tan (2012), the reason for the above-mentioned situation may be that the imported products are not entirely manufactured products produced abroad, but some raw materials or semi-finished products that need to consume domestic resources to continue processing and production. The increase in import trade means that China needs to increase the scale of industrial production, which further aggravates environmental pollution (carbon dioxide emission). In view of the above-presented analysis, this chapter puts forward the following three suggestions: (i) We should optimize the import trade structure and reduce the import of raw materials with high energy consumption and high pollution; (ii) For processing trade links, we need to discard scale expansion and increase environmental constraints on processing trade enterprises; (iii) Increasing import trade based on low carbon and environmentally friendly products can promote carbon emission reduction.

Table 7. Regression Results of PSTR

Variable	Index	Model 1	Model 2
lexp	β_0	0.7250*** (11.9478)	
	β_1	-0.2154*** (-4.0681)	
	β_2	-0.1354* (-1.8031)	
limp	β_0		0.4501*** (8.9046)
	β_1		-0.2154*** (-3.2316)
	β_2		0.0638 (0.8268)
lgpc	β_0	-2.0565*** (-16.5414)	-2.0114*** (-11.5385)
	β_1	0.0022 (0.0445)	-0.0025 (-0.0460)
	β_2	0.2260*** (4.3384)	0.1920*** (3.5133)
lk	β_0	0.3968*** (3.1409)	0.3617*** (2.2987)
	β_1	0.5934*** (5.1662)	0.5564*** (4.2426)
	β_2	-0.2507*** (-2.3142)	-0.4757*** (-3.5175)
f	β_0	-0.1752*** (-4.8503)	-0.1138*** (-2.0633)
	β_1	0.2349*** (4.3065)	0.3986*** (5.2414)
	β_2	-0.1196** (-1.9286)	-0.3185*** (-3.5596)
Other variables	c_1	9156	9287
	c_2	13007	13069
	γ_1	3.9414	2.3623
	γ_2	4.4981	3.3077
	RSS	94.784	121.457

*Note: ***, ** and * are significant at 1%, 5%, and 10% significance levels respectively; the t-statistics corresponding to each coefficient are in () respectively.*

4. Discussion and Conclusion

Based on the achievements of domestic and foreign trade in environmental impact, the general equilibrium model is used to analyze in depth the environmental effects of trade. Based on the direct consumption of energy, the carbon emission coefficient method was used to calculate the carbon emissions in 30 provinces of China. The PSTR model was used to verify and analyze the non-linear relationship between import and export trade and carbon emissions.

The results show that: export trade has a dual-threshold characteristic of carbon dioxide emissions with threshold of economic development level, and shows significant promotion in the three systems. But with the improvement of economic level, on the one hand, the public's demand for the environment has been gradually strengthened, and the awareness of using low-carbon products and low-carbon travel has also been gradually strengthened, and the government's punishment for pollution behavior has increased, on the other hand, the opening up of foreign trade has introduced more high-tech achievements and improved the production technology of China, which has a significant weakening trend. The impact of import trade on carbon dioxide emissions also has a dual-threshold characteristic with the level of economic development as the threshold variable. However, there is a significant effect in the first two systems, that is, when the real GDP per capita is not higher than 13007 yuan, import trade has a significant promoting effect on carbon emissions, and this promotion effect has weakened as the level of economic development has improved. This finding is consistent with the Environmental Kuznets Curve proposed by Grossman *et al*. (1995). With the improvement of economic level, the impact of trade activities on environmental pollution is in a dynamic state.

Although the conclusion shows that in a certain period of time, foreign trade still has a negative impact on carbon emissions of China, it plays a positive role in the Chinese economic development and technological progress, and the improvement of economic level and production technology level caused by trade expansion is conducive to the improvement of domestic environmental quality. In view of this, this paper puts forward the following suggestions: according to local conditions, different regions should carry out different trade policies.

China has a vast territory. The resource endowment and economic level of different regions vary greatly. The development of Eastern China and Western China is extremely unbalanced. According to the empirical results, the higher the level of economic development, the weaker the promotion effect of import and export trade on carbon emissions. For the less developed western regions, we should pay attention to economic development to weaken the impact of trade expansion on carbon emissions, but we should not blindly pursue rapid economic development and ignore the protection of the environment. Therefore, when the relevant policies are formulated in the west, we should not only encourage foreign trade, but also pay attention to the rationalization of trade structure. Due to its unique geographical advantages, the eastern region has a higher degree of opening to the outside world, introduced foreign high-tech, which can promote domestic production technology and make its economy more developed. In this regard, while encouraging trade expansion, it is necessary to strengthen environmental regulation to avoid becoming a pollution haven for other countries.

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