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Relationship between economic growth and SO2 emissions - based on the PSTR model

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Abstract

In this paper, we used the panel smooth transition model (PSTR) to study the nonlinear relationship between sulfur dioxide emissions and economic growth in the three regions of China's eastern, middle and western regions, based on panel data from 31 provinces and autonomous regions in China from 2005 to 2017. And calculated the elasticity of the impact of total export-import volume and urbanization rate on emissions. The empirical results indicate that economic development and sulfur dioxide emissions are positively correlated in the three regions of East, Middle and West. In the eastern region, when the economic scale is lower than the threshold value, it has a negative impact on SO2 emissions; but when it is higher than the threshold value, it has a positive impact on SO2 emissions, and the smoothing rate between the two regime is slow. The per capita GDP in the middle and western regions is weakly positively correlated with SO2 emissions. When the economic scale reaches the threshold value, its positive impact on SO2 emissions will increase, and economic development will further increase emissions.

Keywords: Sulfur dioxide emissions; Economic growth; PSTR; Nonlinear

JEL Classification: D4

1. Introduction

Since the reform and opening-up, China's economic and social development has gone through an extraordinary glorious course of 40 years, and has achieved remarkable historical achievements and achieved unprecedented historical changes. After 40 years of rapid growth, China has become the world's second largest economy after the United States.

However, it is undeniable that the rapid advancement of technological progress and industrialization has greatly improved the material living standards of human beings. The impact of human activities on the environment is growing. And some regions have unilaterally pursued economic growth at the expense of the environment and resources, especially the rapid growth of the industrial economy has led to serious air pollution (Minghui Li et al., 2011). Sulfur dioxide is one of the major pollutants in the atmosphere and an important indicator of whether the atmosphere is contaminated.

There have been many serious incidents of sulfur dioxide damage in many cities around the world, causing many people to be poisoned or killed. The "London Smoke Incident" was caused by a large amount of sulfur dioxide in the air, which led to tragedy. It has become history, but its warnings are far-reaching. Air and water are essential for human survival. Sulfur dioxide in the exhaust gas poses a serious threat to human health and induces many respiratory diseases. Moreover, sulphur dioxide is very soluble in water and its harm is not easily transferred, and the consequences are borne by the emitting countries themselves (Zhaoli Zhang et al., 2012).

Sulfur dioxide is also an important source of acid rain, acid rain has brought serious impacts and damage to the earth's ecological environment and human society and economy.Studies have shown that acid rain has serious harm to human landscapes such as soil, water bodies, forests, buildings, places of interest and historical sites, which not only causes major economic losses, but also endangers human survival and development.

According to the website of China quality inspection, one third of China’s land has been attacked by acid rain. China is a major coal-producing and coal-burning country in the world. The acid rain caused by sulfur dioxide discharged from coal has affected 40% of the national area of nearly 4 million square kilometers and is still expanding. Therefore, analyzing the relationship between economic growth and sulfur dioxide emissions is of practical significance for how to control sulfur dioxide pollution.

2. Literature Review

Some scholars have studied the relationship between economic growth and air pollution. Grossman and Krueger (1991) analyzed whether Nafta would worsen environmental pollution, and found an inverse U-shaped relationship between SO2 and smoke dust and suspended matter, and between SO2 and smoke dust and per capita GDP. And borrowing the relationship between income distribution and economic growth proposed by Simon Kuznets (1955), condensing what is called the "hypothesis of environmental kuznets curve" (EKC), that is, when a country When the level of economic development is low, the degree of environmental pollution is relatively light, but environmental pollution will increase with economic growth.

When the country's economic development reaches a certain level, its environmental pollution level will gradually slow down and the environmental quality will gradually improve. Nektarios Aslanidis (2006) analyzed the panel data of 48 states in the United States from 1929 to 1994 through the PSTR model and found that sulfur dioxide emissions rose steadily at a later stage of economic development and then steadily declined at high income levels. However, for nitrogen oxide emissions, environmental pressures tend to rise with economic growth and then slow down with further growth but do not decline. Anil Markandya (2006) analyzed the relationship between per capita GDP and sulfur emissions in 12 Western European countries over 150 years, as well as the impact of air pollution regulations on the shape of the income-pollution relationship. An inverted U-shaped relationship between per capita GDP and sulfur emissions has been found, and the estimated turning points in most countries are reasonable. In addition, environmental regulations have been found to reduce EKC, and they can also change the turning point of the curve.

Sudong Zhou et al. (2010) conducted an empirical study on the relationship between air pollution and total output value using industry panel data from 1996 to 2007 in Jiangsu Province. The results show that the three air pollutants change in the same direction as the total output value of enterprises, and the larger the total output value, the larger the amount of air pollution is; there are significant differences in air pollution emissions in different industries.

Shenxiang Xie et al. (2012) analyzed the relationship between China's economic growth, FDI investment patterns and sulfur dioxide emissions with the help of China's provincial panel data from 2003 to 2009. Studies have shown that the “environmental Kuznets curve” of economic growth does exist in China, and the “hypothesis of pollution haven” of FDI is not established during the sample period. The increase in FDI has a reduced effect on China's sulfur dioxide emissions as a whole. Tianying Mao et al. (2017) used the EKC model and decomposition analysis method to explore the relationship between industrial SO2 emissions and economic growth in Jiangsu Province from 2003 to 2015.

It is found that with the increase of industrial economy since 1986, the emission of industrial sulfur dioxide in Jiangsu Province has undergone the process of first increasing and then decreasing. Scale and technical effect are the two factors that influence the emission of industrial sulfur dioxide, especially the technical effect plays a dominant role in the realization of industrial sulfur dioxide emission reduction target. Bo Cheng et al. (2018) empirically examined the impact of economic growth on air pollution based on provincial panel data from 2002 to 2012, and examined the regulatory role of institutional environment on the relationship between economic growth and air pollution. The results show that the relationship between economic growth and regional air pollution is inverted U-shape; and the relationship between economic growth and air pollution emission is negatively regulated by public participation and environmental regulation.

Throughout the domestic and international literature, it is found that due to data acquisition problems, few literatures study the relationship between SO2 emissions and economic growth based on time series methods; many literatures on EKC, whether it is panel data model, spatial measurement model, or time series model all adopts quadratic or cubic type. In fact, the transcendental form is essentially linear.

It is controversial to apply the linear model to test nonlinear relationship. The PSTR model first tested the homogeneity of the data, and used LM, LMF, LRT and other statistics to test the linear hypothesis, and modified the model expression to eliminate the homogeneity of the data produced by EKC. Moreover, many models only consider the income when testing the EKC, without considering other control variables, there may be the problem of missing variables.

Based on this, we used the smooth transformation regression model to study the nonlinear change between SO2 emission and economic growth, adding total export-import volume and urbanization rate as control variables. It makes up for the shortage of previous studies using linear model to test the nonlinear relation and missing variable. And studied the relationship between SO2 emissions and economic growth from the perspective of time series, which helps to analyze the relationship between economic growth and pollution emissions from a dynamic perspective.

3. Model

The Smooth Transition Regression Model proposed by Teräsvirta (1994) is an extension of the Smooth Transition Autoregression Model proposed by Hansen (1999), both autoregressive models and other time series models can be applied. By setting a continuous transformation equation that allows variables to smoothly transition between different regimes (Gonzalez et al., 2005), the change in regression parameters is no longer a jump change, but a slow transition, more closely related to the meaning of real economy. The simplest PSTR model with two extreme regimes and a single transition function can be defined as:

$$y_{it} = \mu_i + \beta_0 x_{it} + \beta_1 x_{it} g(q_{it}; r, c) + \beta_2 z_{it} + u_{it} \qquad (1)$$

Where: i=1, ..N stand for the number of panel data individuals; t=1,...T stand for the dimension of time. x_{it} represents the explanatory variable, which is the logarithm of the annual per capita GDP of each province and municipality in China. y_{it} represents the explanatory variable, which is the logarithm of annual SO2 emissions in all provinces and municipalities in China. q_{it} is a conversion variable, which is the logarithm of per capita GDP of every province and municipality in China. z_{it} represents other explanatory variables that may affect SO2 emissions, and the coefficients of these variables do not smoothly transform with the change of the conversion variables. μ_i represents the fixed individual effect. u_{it} is the residual term obey a normal distribution with a mean of 0 and a constant variance.

The transition function $g(q_{it}; r, c)$ is a continuous function of the observable variable q_{it} . Its value is between 0-1, 0 and 1 indicate the two extreme regimes. The function $g(q_{it}; r, c)$proposed by Granger (1993) and Teräsvirta (1994) can be expressed in the form of logistic:

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

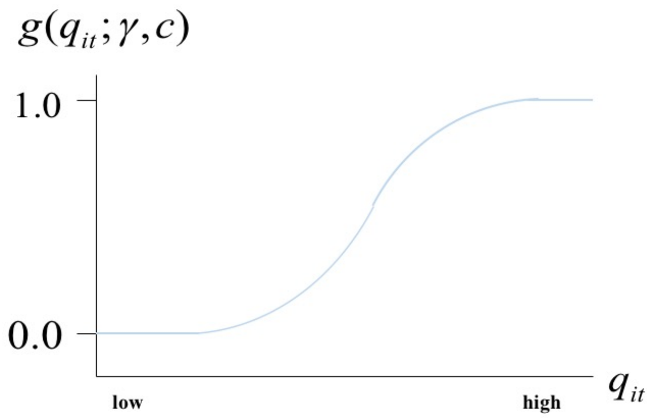
$$\gamma \geq 0 \quad c_m \geq \cdots \geq c_1 \geq c_0 \qquad (2)$$

Where c=(c_1,...c_m) is the location parameter of m, which is the threshold value, González et al. (2005) consider that the location parameter c takes m = 1 or m = 2 to be representative.

When m=1, the form of the transition function is monotonically increasing between 0 and 1, as shown in figure 1: When qit changes from small to large, it corresponds to two extreme regimes, the explanatory variable coefficient is smoothly transformed between β_0 and β_0+β_1.

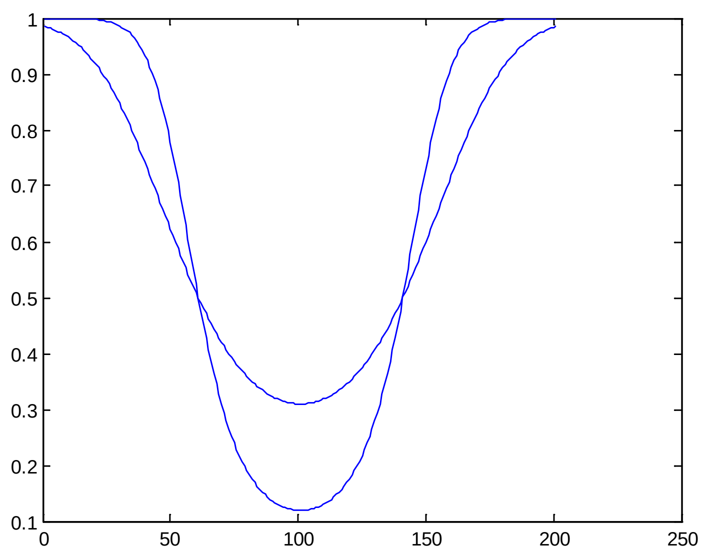
Where the coefficient is β_0 in low regime and β_0+β_1 in high regime.

Figure 1. Transition Function when m=1



When m=2, it can be seen from Fig. 2 that the conversion function $g(q_{it}, \gamma, c_1, c_2)$ takes the minimum value at $(c_1+c_2)/2$, and the value ranges from 0 to 0.5. When q_{it} is minimum and maximum, the conversion function are both 1. then the model has three extreme mechanisms, it becomes a three-institutional model when $\gamma \to \infty$. the distribution on both sides is called the external regime, and the distribution in the middle is called the intermediate regime.

Figure 2. Transition Function when m=2



$\gamma > 0$ is a smoothing parameter, controlling the speed of conversion function, the higher the value, the faster the conversion. If $\gamma \to \infty$, then the conversion speed is infinite, and the function has a discontinuity between the two extreme systems, the value of the conversion equation can only be 0 or 1, and the model degenerates into Hansen's PTR model. If $\gamma = 0$, the conversion equation degenerates into a homogeneous or linearly corrected panel regression.

The PSTR model setting process consists of three steps: The first step is to perform a linear verification of the model. Since the transformation equations in the model contain unknown parameters, here we refer to the method of Hansen (1996), replacing the transformation equation with a first-order Taylor formula. The model expression is converted to the following auxiliary regression equation:

$$y_{it} = \mu_i + \beta_0^* x_{it} + \beta_1^* x_{it} q_{it} + \cdots + \beta_m^* x_{it} q_{it}^m + \beta_{m+1} z_{it} + u_{it}^* \qquad (3)$$

PSTR model constructs the parametric linear auxiliary regression equation, estimates the equation and the linear fixed-effects model respectively, and tests the statistic which is calculated according to the sum of their residual squares. The original hypothesis is $H_0 : \beta_1 = \beta_2 = \beta_3 = 0$, The corresponding assumptions are $H_{01}^*: \beta_1^* = 0|\beta_3^* = \beta_2^* = 0$, $H_{02}^*: \beta_1^* = 0|\beta_3^* = 0$, $H_{03}^*: \beta_3^* = 0$. We use TY chang's method to test the above hypothesis through Wald Tests, Fisher Tests, and LRT Tests. The statistics are LM, LMF and LRT, respectively. The expression is as follows:

$$LM = NT(SSR_0 - SSR_1)/SSR_0 \qquad (4)$$

$$LMF = [(SSR_0 - SSR_1)/(mK)]/[SSR_1/NT - N - m(k+1)] \qquad (5)$$

$$LRT = NT[\log(SSR_0) - \log(SSR_1)] \qquad (6)$$

SSR_0 and SSR_1 are the sum of squared residuals for the original hypothesis and the alternative hypothesis, respectively, and K is the number of explanatory variables. The original hypothesis is accepted, the coefficients before the explanatory variables are all 0, then the relationship between the them are linearly homogeneous. If the original hypothesis is rejected, the panel data has cross-sectional heterogeneity, and there is a transition between different regimes in the model. The PSTR model can be used to continue to analyze. The results are different: when H_{01}^* or H_{03}^* is rejected, then m=1; when H_{02}^* is rejected, then m=2.

After determining the value of m, the Nonlinear Least Squares estimate is used to get the parameter β_0 and β1, r, γ and c.

4. Data

4.1 Basis for the division of the Eastern, central and Western Regions

In this paper, according to the classification standards issued by the National Bureau of Statistics of the People's Republic of China in 2003, the mainland of China is divided into three economic regions: East, Middle and West according to the level of economic development and geographical location. However, in 2004, China carried out the western development strategy, and divided the two ethnic autonomous regions of Guangxi and Inner Mongolia into the western regions in the sense of national development.

Therefore, the Eastern region (11) includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the Middle region (8) is Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, and Hubei. Hunan; the Western region (12) includes Sichuan, Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi, and Inner Mongolia.

4.2 Indicator selection and data description

The main data of the empirical study is the Natural Logarithm of SO2 emission and the Natural logarithm of per capita income. Per capita income is usually expressed as per capita disposable income or per capita GDP, but setting only one exogenous variable in the econometrics can easily lead to large errors in the model. While taking into account the quantitative and data availability of other factors. This article joins the two indicators of total import-export volume and urbanization rate of each province or municipality.

According to the availability of the data, we compiled the data for each variable from 2005 to 2017. The explanation of each indicator is shown in Table 1. The data comes from the China Statistical Yearbook. Table 2 Table 3 Table 4 Table 5 describes the statistical characteristics of each variable in the model.

Table 1. Explanation of each indicator and unit description

Variable	Definition	Unit of measurement
SO2 emissions (SO2)	SO2 emission	10 ton
GDP per capita (GDP)	GDP divided by the population	10 yuan per capita
Trade	Total import and export	10^4yuan

Urbanization rate(URBR)	Urban population/Total population	%

Table 2. Summary statistics of LnSO2

Region	Countries	Mean	Max.	Min.	Std.dev.	Skew.	Kurt.	J.-B.
East	Beijing	11.40792	12.15478	9.907748	0.635155	-1.170118	3.696277	3.229148
	Tianjin	12.14687	12.48749	10.92673	0.499139	-1.830179	4.630745	8.697838
	Hebei	13.99956	14.25053	13.30862	0.270133	-1.588975	4.554319	6.779107
	Liaoning	13.76633	14.04583	12.87316	0.351534	-1.79065	4.776582	8.656891
	Shanghai	12.32996	13.14803	9.825647	0.935978	-1.587766	4.995865	7.619885
	Jiangsu	13.75972	14.13251	12.9256	0.335225	-1.382933	4.185999	4.905662
	Zhejiang	13.26748	13.66469	12.15724	0.446686	-1.589321	4.382	6.507418
	Fujian	12.76204	13.05836	11.80478	0.369345	-1.759505	4.853445	8.568459
	Shandong	14.25844	14.50966	13.51322	0.26571	-1.882617	5.919153	12.29499
	Guangdong	13.60292	14.07325	12.53096	0.47642	-1.176349	3.377856	3.075561
	Hainan	10.13819	10.43813	9.566019	0.274504	-0.703991	2.508393	1.204714
Middle	Shanxi	13.97394	14.23159	13.25878	0.291376	-1.66574	4.418347	7.101506
	Jilin	12.73753	12.93166	12.0204	0.295574	-1.844471	4.64558	8.837956
	Heilongjiang	13.04787	13.16522	12.59018	0.178409	-1.840887	4.867278	9.231185
	Anhui	13.07471	13.27766	12.36912	0.282038	-1.810707	4.704115	8.67677
	Jiangxi	13.13162	13.3598	12.28055	0.330549	-1.904837	5.005353	10.03982
	Henan	13.91956	14.3004	12.56485	0.536205	-1.827324	4.786767	8.964038
	Hubei	13.23518	13.54107	12.30165	0.370763	-1.776685	4.69493	8.395415
	Hunan	13.3765	13.74723	12.27646	0.423653	-1.590831	4.680096	7.012252
West	Sichuan	13.69174	14.07787	12.8717	0.370569	-1.004313	3.056787	2.187142
	Chongqing	13.27299	13.66469	12.44265	0.390098	-1.05045	3.071541	2.39357
	Guizhou	13.86153	14.19737	13.3802	0.254374	-0.600586	2.390178	0.982962
	Yunnan	13.22208	13.44622	12.85957	0.161379	-0.472743	3.075179	0.487281
	Xizang	8.055896	8.596265	7.414573	0.43294	-0.285035	1.44181	1.491174
	Shangxi	13.49169	13.79633	12.54025	0.403202	-1.759172	4.431506	7.815138
	Gansu	13.10963	13.34375	12.46385	0.281988	-1.74611	4.362772	7.611907
	Qinghai	11.81736	11.96205	11.43406	0.151831	-1.26384	4.103279	4.120126
	Ningxia	12.72637	12.92485	12.24298	0.205839	-1.338284	3.706656	4.150995
	Xinjiang	13.34675	13.65649	12.94367	0.227669	-0.070492	1.86549	0.707953
	Guangxi	13.24994	13.83923	12.0857	0.593352	-0.787982	2.518977	1.470649
	Inner Mongolia	14.01565	14.25827	13.21084	0.332823	-1.835818	4.614876	8.714735

Note: 1. The sample period is from 2005 to 2017.
*** indicates significance at the 0.01 level.

Table 3. Summary statistics of LnGDP

Region	Countries	Mean	Max.	Min.	Std.dev.	Skew.	Kurt.	J.-B.
East	Beijing	11.27824	11.76752	10.72424	0.324524	-0.199913	2.002035	0.626056
	Tianjin	11.22367	11.68641	10.48523	0.407948	-0.545805	1.938147	1.256202
	Hebei	10.28772	10.72298	9.601166	0.377438	-0.55265	1.919696	1.293902
	Liaoning	10.63124	11.08757	9.851299	0.423966	-0.616897	2.014477	1.350649
	Shanghai	11.29862	11.74906	10.84883	0.27472	0.023865	1.999413	0.543537
	Jiangsu	10.93347	11.58199	10.10887	0.47973	-0.330838	1.844717	0.960101
	Zhejiang	10.8999	11.43016	10.2293	0.38733	-0.317602	1.860707	0.921631
	Fujian	10.66133	11.3227	9.833387	0.492481	-0.319681	1.802176	0.998597
	Shandong	10.66946	11.19557	9.908276	0.422685	-0.447123	1.936976	1.045251
	Guangdong	10.76877	11.30136	10.10377	0.375591	-0.304925	1.97847	0.766697
	Hainan	10.14519	10.78787	9.293854	0.502128	-0.350543	1.752446	1.109287
Middle	Shanxi	10.16878	10.64685	9.433084	0.389529	-0.678022	2.151111	1.386377
	Jilin	10.39358	10.91214	9.499122	0.493085	-0.570144	1.921776	1.334028
	Heilongjiang	10.24205	10.64342	9.577342	0.378383	-0.510973	1.764188	1.392952
	Anhui	9.992663	10.67824	9.067624	0.547397	-0.392105	1.747224	1.183234
	Jiangxi	10.0297	10.67877	9.152711	0.515052	-0.386451	1.805502	1.096444
	Henan	10.15206	10.75094	9.336621	0.458457	-0.416151	1.925416	1.000705
	Hubei	10.29891	11.00541	9.344084	0.561422	-0.385144	1.802125	1.098634
	Hunan	10.16513	10.8109	9.252058	0.528679	-0.439012	1.849134	1.135019
West	Sichuan	10.02745	10.70663	9.111624	0.531682	-0.400204	1.807938	1.116735
	Chongqing	10.3086	11.05788	9.304013	0.585449	-0.39481	1.880361	1.016758
	Guizhou	9.632586	10.54418	8.527539	0.668824	-0.260939	1.815791	0.907133
	Yunnan	9.787205	10.44059	8.966356	0.496163	-0.27281	1.71581	1.054541
	Xizang	9.882453	10.57814	9.117567	0.481813	-0.103784	1.71732	0.914525
	Shangxi	10.25311	10.95546	9.200189	0.584708	-0.525629	1.947505	1.198649
	Gansu	9.746307	10.25755	8.919587	0.465926	-0.473006	1.81305	1.247885
	Qinghai	10.13575	10.69301	9.21483	0.516792	-0.514591	1.873506	1.261111
	Ningxia	10.20962	10.83496	9.233959	0.541865	-0.581739	1.973769	1.303701
	Xinjiang	10.1968	10.71311	9.480978	0.428564	-0.356929	1.645365	1.270007
	Guangxi	9.969331	10.54802	9.081142	0.516828	-0.42649	1.747148	1.244324

	Inner Mongolia	10.71966	11.18531	9.70082	0.513156	-0.847132	2.332434	1.796262

Note: 1. The sample period is from 2005 to 2017.
*** indicates significance at the 0.01 level.

Table 4. Summary statistics of LnTrade

Region	Countries	Mean	Max.	Min.	Std.dev.	Skew.	Kurt.	J.-B.
East	Beijing	19.05579	19.39782	18.4484	0.29963	-0.634323	2.346946	1.102803
	Tianjin	17.94056	18.2252	17.59064	0.217559	-0.332466	1.825216	0.987054
	Hebei	17.07964	17.4205	16.39302	0.341247	-0.952011	2.48782	2.105797
	Liaoning	17.80246	18.07676	17.32994	0.239433	-0.625074	2.216539	1.179037
	Shanghai	19.30608	19.58841	18.8436	0.222156	-0.771198	2.452125	1.451208
	Jiangsu	19.51243	19.80475	19.04505	0.221478	-0.787808	2.534094	1.462301
	Zhejiang	18.94667	19.35735	18.29251	0.318916	-0.676383	2.350567	1.219692
	Fujian	18.1716	18.56458	17.61262	0.346009	-0.357425	1.469905	1.544943
	Shandong	18.63556	18.9951	17.95642	0.336841	-0.760545	2.274375	1.538465
	Guangdong	18.1884	18.50831	17.57197	0.303418	-0.692466	2.237804	1.353613
	Hainan	15.47687	16.09217	14.54913	0.58943	-0.457949	1.516797	1.645996
Middle	Shanxi	15.94755	16.26603	15.32906	0.292443	-1.102853	2.841323	2.648919
	Jilin	14.26264	14.78556	13.38898	0.452226	-0.623243	2.228245	1.164223
	Heilongjiang	14.60635	15.17394	13.77114	0.457797	-0.105928	2.007123	0.558289
	Anhui	16.73301	17.40496	15.82645	0.517038	-0.335856	1.730144	1.117854
	Jiangxi	16.4523	17.21756	15.01836	0.724959	-0.697998	2.159329	1.438412
	Henan	16.80474	17.77447	15.6605	0.779919	-0.094525	1.366969	1.463871
	Hubei	14.75629	15.34825	13.71622	0.545182	-0.609396	2.057784	1.285498
	Hunan	16.2408	17.00748	15.40784	0.504542	-0.172772	1.783202	0.866665
West	Sichuan	16.91902	17.64403	15.68316	0.650723	-0.62541	2.049591	1.336739
	Chongqing	16.56852	17.88662	15.073	1.073427	-0.111497	1.276097	1.636682
	Guizhou	14.90577	15.84523	13.95507	0.635809	-0.041664	1.662841	0.972258
	Yunnan	16.07042	16.71623	15.17281	0.513067	-0.359405	1.732374	1.150264
	Xizang	13.2855	14.58631	12.03358	0.787361	0.283974	2.186123	0.53352
	Shangxi	16.0537	17.11517	15.13706	0.639132	0.16916	1.77223	0.878517
	Gansu	15.25057	15.6623	14.58314	0.32484	-0.748165	2.475608	1.361744
	Qinghai	13.32998	14.00188	12.73248	0.40646	0.334126	1.822093	0.99343
	Ningxia	14.26934	15.03944	13.58205	0.467158	0.273352	2.137688	0.56467
	Xinjiang	16.30542	16.65279	15.68802	0.310253	-0.735424	2.488204	1.313719

	Guangxi	16.4679	17.46947	15.26114	0.712465	-0.214689	1.862322	0.80095
	Inner Mongolia	15.69255	16.05439	15.20042	0.263396	-0.46257	2.127762	0.875703

Note: 1. The sample period is from 2005 to 2017.

⍰⍰⍰ indicates significance at the 0.01 level.

Table 5. Summary statistics of URBR(%)

Region	Countries	Mean	Max.	Min.	Std.dev.	Skew.	Kurt.	J.-B.
East	Beijing	158.3441	418.097	15.5708	121.4965	0.928257	2.893939	1.873027
	Tianjin	79.7392	82.91586	75.07191	2.923403	-0.369549	1.568638	1.405659
	Hebei	45.87144	55	37.68793	5.459511	0.122747	1.969265	0.608119
	Liaoning	63.44471	67.49828	58.70647	3.625045	-0.13127	1.291997	1.617525
	Shanghai	88.76733	89.60663	87.61905	0.682001	-0.476366	1.968602	1.067886
	Jiangsu	60.25579	68.76323	50.50079	6.383886	-0.230781	1.571778	1.220297
	Zhejiang	61.69307	68.00424	56.02084	4.215387	-0.020245	1.558132	1.127004
	Fujian	57.51316	64.79161	49.39556	5.239292	-0.21827	1.682459	1.04351
	Shandong	51.71065	60.58365	45.00433	5.082608	0.373809	1.899258	0.959055
	Guangdong	65.93756	69.85406	60.68088	2.897922	-0.326558	1.823129	0.981276
	Hainan	51.07475	57.99136	45.16908	4.055101	0.238477	1.963163	0.705529
Middle	Shanxi	49.55093	57.34738	42.11624	5.231828	0.027491	1.610412	1.047572
	Jilin	54.04384	56.64336	52.50368	1.270965	0.852322	2.480011	1.720442
	Heilongjiang	56.40237	59.38242	53.08901	2.12859	-0.104616	1.821078	0.776553
	Anhui	44.70937	53.49321	35.50654	5.791745	-0.067274	1.810711	0.775944
	Jiangxi	45.82465	54.60839	36.99838	5.702497	-0.004252	1.774506	0.813534
	Henan	40.55433	50.16215	30.65032	6.228425	-0.030595	1.832268	0.740643
	Hubei	50.92111	59.30193	43.2049	5.861561	-0.034267	1.470627	1.269492
	Hunan	45.54439	54.62099	37.00601	5.414313	0.112765	1.98501	0.585578
West	Sichuan	41.80296	50.79499	33.00049	5.8243	0.000401	1.756437	0.83766
	Chongqing	54.79562	64.09756	45.21086	6.2055	-0.058605	1.736328	0.872411
	Guizhou	35.14032	46.03352	26.86327	6.588372	0.234948	1.729096	0.994499
	Yunnan	37.43203	46.67778	29.50562	5.726939	0.169661	1.702972	0.973603
	Xizang	24.10394	30.86053	20.71429	3.341875	0.974092	2.536274	2.172332
	Shangxi	47.34943	56.7927	37.23577	6.497571	-0.077606	1.672742	0.967257
	Gansu	37.68553	46.38233	30.01965	5.300421	0.147227	1.816635	0.805488
	Qinghai	45.6132	53.01003	39.22652	4.928014	-0.020277	1.55245	1.1359
	Ningxia	49.54168	57.91789	42.28188	5.263644	0.122739	1.69267	0.95841
	Xinjiang	43.06113	49.36605	37.16418	4.036892	0.039181	1.739661	0.863738
	Guangxi	41.7229	49.21187	33.62661	5.194049	-0.107108	1.729232	0.899567

Inner Mongolia	55.59072	62.00079	47.19101	4.944432	-0.367171	1.802729	1.068555

Note: 1. The sample period is from 2005 to 2017.
□□□ indicates significance at the 0.01 level.

5. Results

5.1 Nonlinear test and model form determination

We use Matlab software programming to achieve the following model steps. In the PSTR model, the first step is to verify whether there is a conversion between different regimes in the panel data.

If the linear hypothesis is rejected, then the relationship is nonlinear, thus further determining the number of regimes, that is, the number of transformation equations. The results are shown in Table 6:

Table 6. Results of linearity tests

Hypothesis	**Region**	**Nonlinear test statistic**	**P-value**
H0: Linear Model H1: PSTR model with at least one Threshold Variable (r=1)	East	Wald Tests (LM): 72.459	0
		Fisher Tests (LMF)：14.038	0
		LRT Tests (LRT):101.050	0
	Middle	Wald Tests (LM): 62.023	0
		Fisher Tests (LMF)：14.283	0
		LRT Tests (LRT):94.357	0
	West	Wald Tests (LM): 45.786	0
		Fisher Tests (LMF)：6.231	0
		LRT Tests (LRT): 54.200	0

The statistical values of P in the East, Middle and West are all 0, which means that the original hypothesis is rejected on the significance level of 1%. There is heterogeneity in the sample observation data, the model is nonlinear and there is at least one threshold value. This shows that the panel smooth transformation model can better describe the nonlinear characteristics of per capita GDP to SO2 emissions.

The second step of the model is to determine the form of the transformation equation, expand the transformation equation by first-order Taylor at r=0, and calculate the F statistics to test H_{01}, H_{02}, H_{03} respectively, to determine the shape of the transformation equation. The results is shown in Table 7:

Table 7. Results of model tests

Hypothesis	Region	F-statistic	m
H_{01}:B1=0|B2=B3=0. H_{02}:B2=0|B3=0. H_{03}:B3=0.	East	F3 = 3.003（0.003） F2 = 2.757（0.006） F1 = 5.569（5.569）	m=1
	Middle	F3 = 2.119（0.036） F2 = 5.319（0.000） F1 = 3.375（0.001）	m=2
	West	F3 = 0.366（0.949） F2 = 1.127（0.348） F1 = 4.497（0.000）	m=1

Note: The p value of the F statistic in parentheses.

According to the test results, the conversion equations in the east and west are logical, and the model only contains one location parameter; the conversion equation in the middle is exponential, and there are two location parameters in the model.

Secondly, determining the number of conversion intervals--r, that is, determining the number of conversion functions in the model. Three statistics methods of linear test are also used to test the original hypothesis H_0: r=a and alternative hypothesis H_1: r=a+1.

If the original hypothesis can not be rejected, then the model contains a transformation equation, whereas the PSTR model contains at least (a + 1) transformation equation.

Then set the original hypothesis H_0: r=a+1 and the alternative hypothesis H_1: r=a+2, and repeat the above process until all the statistics accept the original hypothesis. Where the value of r is the number of transition functions of the model.

Table 8. Results of no remaining heterogeneity tests

Hypothesis		**Region**	**Nonlinear test statistic**	**r**
H0:r=a	H1:r=a+1	East	Wald Tests (LM): 7.543 (0.056) Fisher Tests (LMF): 2.283 (0.082) LRT Tests (LRT): 7.749 (0.051)	r=1
		Middle	Wald Tests (LM): 14.103 (0.029) Fisher Tests (LMF): 2.196 (0.051) LRT Tests (LRT):15.156 (0.019)	r=1
		West	Wald Tests (LM): 2.745 (0.433)	r=1

Fisher Tests (LMF) ： 0.806
（0.493）
LRT Tests (LRT): 2.770
（0.429）

Note: The p value of the F statistic in parentheses.

The results in Table 8 show that the East, Middle and West models all accept the original assumption, r is 1, so there is no need to further test, the model only contains a conversion equation. Thus, the final form of the PSTR model for the East and West is determined as:

$$LNSO2_{it}=\mu_I+\beta_0 LNGDP_{it}+\beta_1 LNGDP_{it} g(q_{it};\gamma;c)+\beta_2 LNTrade_{it}+\beta_3 URBR_{it}+u_{it} \quad (8)$$

The final form of the PSTR model for the Middle is determined as:

$$LNSO2_{it}=\mu_I+\beta_0 LNGDP_{it}+\beta_1 LNGDP_{it} g(q_{it};\gamma;c_1;c_2)+\beta_2 LNTrade_{it}+\beta_3 URBR_{it}+u_{it} \quad (9)$$

5.2 Estimation of model parameters and results description

In order to estimate the nonlinear transformation of the PSTR model, we use Nonlinear Least Squares (NLS).

The smoothing parameter γ and the location parameter c are first determined and brought into the models to obtain the estimates value of other parameters. The estimated values of the parameters in the model of East, Middle and West are shown in the following table:

Table 9. Parameter estimates for the final PSTR models

	East		**Middle**		**West**	
	LNGDP< -51.6579	LNGDP> -51.6579	LNGDP< -1.2908 Or LNGDP> 0.0000	0.0000 >LNGDP> -1.2908	LNGDP< 10.1250	LNGDP> 10.1250
β_{GDP}	-1.7861	1.7861	0.0014	1.1212	0.0509	0.7114
SD	1.1786	1.2294	0.1225	0.7499	0.2187	0.0982
T-statistic	−1.5155	1.4529	0.0112	1.4951	0.2330	7.2459***

βTrade	0.0082	-0.0082	0.2082	-0.9696	0.0681	-0.2282
SD	0.0147	0.0147	0.0609	0.2593	0.0616	0.0603
T-statistic	0.5549	−0.5548	3.4172***	−3.7396***	1.1054	-3.7837***
β_{URB}	0.0001	-0.0001	-0.0332	0.0190	-0.0975	-0.0524
SD	0.0009	0.0009	0.0115	0.0897	0.0142	0.0088
T-statistic	0.0922	-0.0905	−2.8800***	0.2119	-6.8548***	−5.9639***
c	-51.6579		-1.2908	0.0000	10.1250	
r	0.1960		6.0137e-07		2.2101	
RSS	10.022		2.275		5.861	

Note: *** stand for 1% significant level.

in Table 9, the individual parameters passed the T-test in the model have economic explanatory significance. We can see that:

(1) The effect of economic growth on SO2 emission is different in East, Middle and West Regions. The emission of SO2 changes smoothly with per capita GDP between high and low regimes. Specifically, in the East region, the mechanism transition occurs when the location parameter of the model has a logarithm of -51.6579.

In the Middle region, the mechanism transition occurs when the location parameter of the model has a logarithm of -1.2908 and 0.0000. Finally, in the West region, the mechanism conversion occurs when the location parameter of the model is 10.1250.

The elasticity value of SO2 emissions is 0.0509 when the economic development is in a low regime, which is positively related. When the per capita GDP of the region gradually increases and is greater than this location parameter, the elasticity coefficient of emissions becomes 0.7114, and economic development will be increase SO2 emissions to a certain extent.

(2) In the East, Middle and West provinces, the relationship between total export-import volume and SO2 emission is positive first and then negative.

(3) In the East provinces, the effect of urbanization rate on SO2 emission is positive first and then negative, while in the Middle and West provinces, the effect of urbanization rate on SO2 emission is just opposite to that in the East, it is negative first and then positive.

Figures 3, 4, and 5 show the transfer function images of the three models. The smoothing parameter A determines the conversion speed between different economic regimes. It can be seen that the conversion speeds in the East and Middle regions are relatively slow, with γ being 0.1960 and 6.0137e-07, respectively, while the γ in West region is 2.2101. Therefore, there is obvious mechanism conversion characteristics. That is, after the economic development of the western cities reaches a certain scale, its effect on SO2 emissions will be smoothly converted from a high regime to a low regime; while the speed of transition between regimes in East and West region is slow.

Figure 3. Transition Function Plot of East

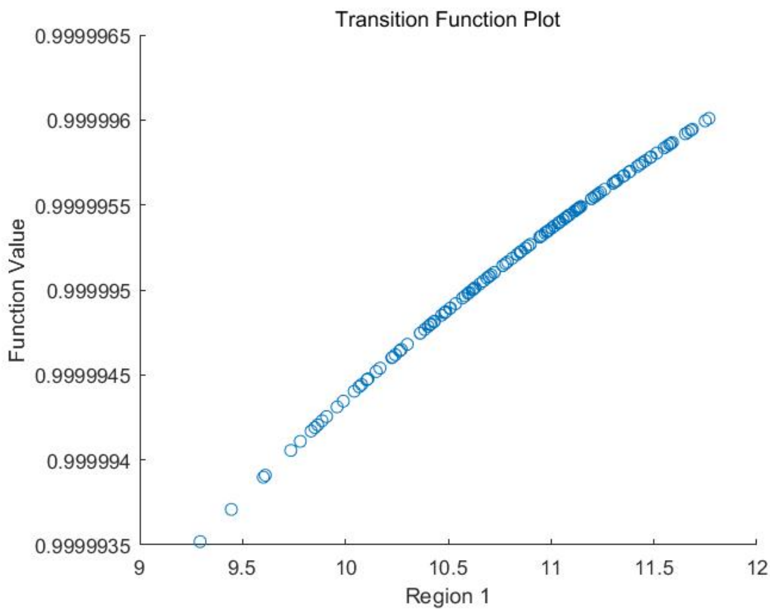


Figure 4. Transition Function Plot of Middle

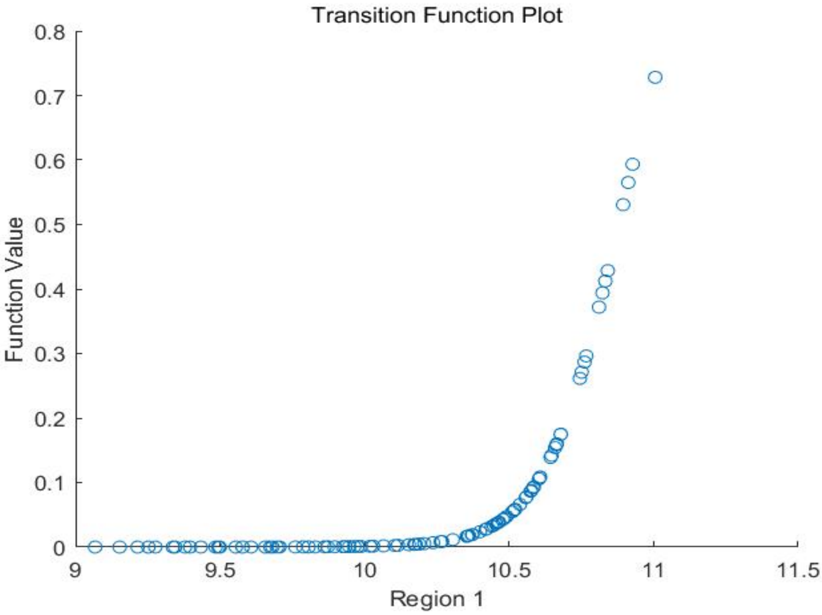
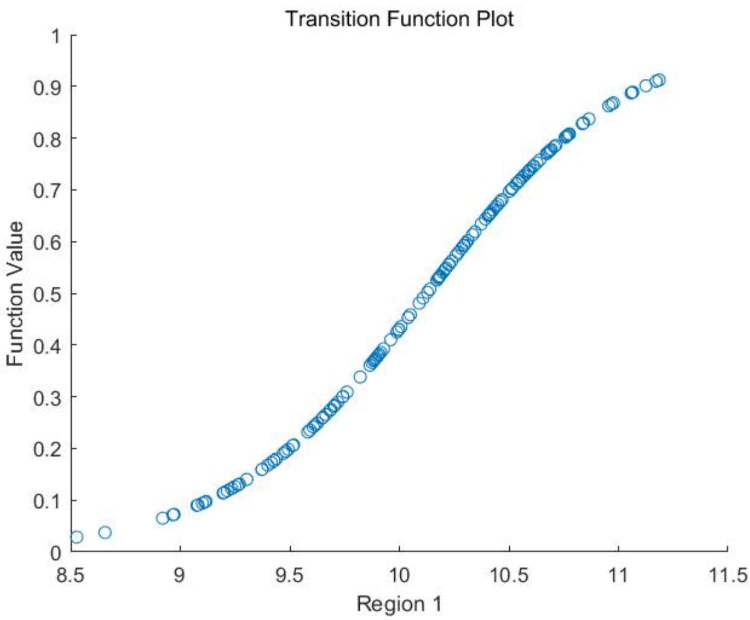


Figure 5. Transition Function Plot of West



6. **Discussion, and Conclusions**

In this paper we have two main contributions. First, a nonlinear panel smooth transition regression (PSTR) model is constructed, which allows the regression coefficients to change gradually from one group to another.

That is, the parameters in the model can be changed continuously and gradually smoothly between different extreme regions with a function containing exogenous variable. This feature is consistent with the characteristics of changes in SO2 emissions. Its changes are not rapid and will change with the economic growth of a certain region, the total imports-exports volume, and urbanization rate gradually.

Secondly, based on the smooth transition regression model (PSTR) proposed by Gonzalez et al., the paper quantifies economic growth by using per capita GDP as the threshold variable. The model is firstly applied to analyze the effect of economic growth on SO2 emission in the three regions of East, Middle and West of China.

The results show that the situation in the East, Middle and West is different, but both indicate that there is a nonlinear vertical and horizontal smooth moving relationship, especially in the West.The Western region found that when per capita GDP is below the threshold value of per capita GDP of 24,959 yuan, per capita GDP is weakly positively correlated with SO2 emissions.

When the economic scale reaches the per capita GDP threshold value of per capita GDP of 24,959 yuan, its positive impact on the emission of SO2 will increase. Economic development has exacerbated emissions.

The natural carrying capacity of the western region is relatively weak. Along with the economic growth brought about by the government's policy of "China's Western Development Program" , attention should also be paid to investment in the ecological field. For example, using the characteristics of geographical conditions to strengthen forestry development to reduce emissions, and actively developing wind energy, solar energy and other energy to improve the structure of traditional energy consumption, these will bring many economic and social benefits.

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