

# Research Article

# Impact of Sino-US Trade Liberalization on China's Carbon Emissions and Future Works on Fractional Phenomenon

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This study estimates the effects of the Sino-US trade liberalization on  $CO_2$  emissions in China and its influencing mechanism. We used the exchange of CNY/USD as the instrumental variable to alleviate the endogeneity with the two-stage least squares method. Different from the existing literature focusing on implied carbon, we use panel data of 27 provinces in China from 1998 to 2018 to examine the relationship between the Sino-US trade liberalization and  $CO_2$  emissions. We found that the Sino-US trade liberalization had a positive effect on the environment and reduced  $CO_2$  emissions.

# 1. Introduction

China's entry into the World Trade Organization (WTO) in 2001 boosted the growth of its international trade. Figure 1 shows that the country's total import and export volume increased from USD 474.297 billion in 2000 to USD 4577.245 billion in 2019 (data source: Website of General Administration of Customs of China). Exports also feature prominently in the troika and become the engine of economic growth. China's share of global exports rose from 3.9% in 2001 to 12.8% in 2018, and its rank in global exports rose from 26th in 1980 to 1st in 2018 (data source: China Foreign Trade Statistics Yearbook). Figure 2 shows that the US has been China's largest trading partner and largest export destination in recent years.

At the same time,  $CO_2$  emissions and global warming became common global concerns. The Carbon Dioxide Information Analysis Center reported that the  $CO_2$  concentration in the atmosphere was 316 ppm in 1959, 325 ppm in 1970, 354 ppm in 1990, and 410 ppm in 2018. The amount of  $CO_2$  in the atmosphere could double by the middle of the twenty-first century. China has become the world's biggest emitter. China's carbon emission rose from 26 thousand metric tons in 1899 to 2806634 metric tons in 2014 according to CDIAC (Carbon Dioxide Information Analysis Center). And its  $CO_2$  emissions have increased from 3214.1 million tons in 2000 to 9729.12 million tons in 2017 according to CEADS (China Emission Accounts and Datasets).

If  $CO_2$  and other green house gas increase too much, then excessive heat will remain in the atmosphere. This phenomenon will make the Earth excessively hot and cause dramatic changes to the climate. Consequently, life on Earth will suffer severely. A rise in average global temperatures by 2°C to 3°C would bring disaster to the planet in the form of melting ice caps, flooding of coastal areas, loss of species, and increased extreme weather.

The debate over the environmental effects of open trade has lasted a long time between free trade supporters and environmentalists. Proponents of free trade argued that liberalization promotes economic growth, expands the pie, increases economic welfare, and spreads the benefits to all parties involved in international trade. Environmentalists retaliated that the expansion of international trade pollutes the environment and increases  $CO_2$  emissions.

This study attempts to study the effects of Sino-US trade liberalization on  $CO_2$  emissions. The remainder of this study is arranged as follows. Section 2 is the literature review. Section 3 is the model setting and data



FIGURE 1: China's total import and export and growth rate from 2000 to 2019. Source: Yearbook of Foreign Economic Statistics of China.



FIGURE 2: China's top 10 trade partners in 2019. Source: General Administration of Customs of China.

introduction. Section 4 presents the regression results. Section 5 is the conclusion.

# 2. Literature Review

Studies have not yet reached a consensus on the effects of trade liberalization on  $CO_2$  emissions. Some of them believe that trade opening is conducive to the improvement of the environment [1–5]. Antweiler et al. [6] used data of  $SO_2$  concentration to measure from the three aspects of scale, structural, and technological effects and found that free trade improved the environment. Frankel and Rose [7] investigated the effects of trade liberalization on environmental pollution and found that the results are against the "pollution paradise hypothesis." They proved that trade liberalization reduced  $SO_2$  emissions. Baghdadi et al. [8] used the panel data of many countries for nearly 30 years. They

explored the effect of trade opening on pollution emission and determined that trade opening helped reduce CO<sub>2</sub> emissions. Destek et al. [9] found that trade openness reduced the environmental degradation of EU countries. Saud et al. [10] analyzed the impact of financial development, foreign direct investment, economic growth, electricity consumption, and trade openness on environmental quality with the panel of 59 Belt and Road Initiative (BRI) countries. The results showed that the improvement of trade openness had improved the quality of the environment. Muhammad et al. [11] explored the nexus between greenhouse gas, financial development, energy consumption, trade, and urbanization in 34 upper middle income countries from Asia, Europe, Africa, and America (South and North). The results highlighted the role of trade openness in reducing greenhouse gas emissions in various regions. Chinese scholars [12-20] also drew a similar conclusion that the "pollution paradise hypothesis" does not exist in China by using data from the country.

By contrast, other studies suggest that trade liberalization has worsened environmental quality and degraded the environment. Lanouar [21] used total ecological footprint and ecological carbon footprint as new indicators of environmental degradation and found that trade openness was not conducive to the improvement of environmental quality with the latest data. Solarin et al. [22] also selected the index of ecological footprint to explore the relationship between trade openness and environment in Nigeria. The results show that trade openness further worsens environmental quality in both short and long term. Thai Ha Le [23] took PM10 as the basic indicator of environmental quality to examine the relationship between trade openness and environment. The results differed according to the income of countries. Trade openness had a benign effect on the environment in high-income countries but a harmful effect in middle- and low-income countries. This result was consistent with the popular notion that rich countries dumped their pollution to poor countries. Yu and Peng [24] analyzed the effects of trade liberalization on China's trade transfer emissions and total CO<sub>2</sub> emissions and verified the "consumption in developed countries and pollution in China."

Scholars also believed that the relationship between trade liberalization and the environment is uncertain. The effects of trade liberalization on the environment are not merely positive or negative but a complex result with positive and negative effects [25-28]. Copeland and Taylor [29] studied the north-south trade and found that trade liberalization had a negative effect on the environment in developed countries and a negative effect in developing countries. Mohd et al. [30] examined whether international trade hindered environmental quality with panel data from 1991 to 2016 in thirty-five Asian countries. They found that the scale effect significantly and positively increases ecological footprint while technique effect has negative impact on ecological footprint which lowers environmental degradation in all Asian income group countries. Hayat et al. [31] investigated the impact of trade openness on carbon emission in developed and developing countries from 1985 to 2018. The study found that the impact of trade liberalization on environmental quality was uncertain. Trade openness had been found to have a decreasing effect on carbon emission in developed countries while degrading the quality of environment in developing countries. Wang and Wang [32] analyzed the effect of trade liberalization on the environment by using a dynamic panel model. The results showed regional differences in the environmental effect of trade liberalization. Trade liberalization will improve the environmental quality in the eastern region and increase pollution in the western region.

The above literature indicated the absence of a consistent conclusion on the effects of trade liberalization on the environment. Therefore, the universality of the conclusion is controversial. Endogeneity has been a concern among the empirical analysis in the previous literature, but no reliable solution to this problem has been proposed. Empirical research from China also lacks explanations of the influencing mechanism.

Studies on the relationship between the Sino-US trade liberalization and  $CO_2$  emissions focus on using the inputoutput model to calculate implied carbon [15, 33–39]. The main problems of using the input-output analysis to calculate trade implied carbon are as follows. First, the inputoutput table is a tool and a fundamental basis for calculating implied carbon. However, compiling the input-output table takes considerable time and is done every five years. Some documents have been extended in accordance with the official input-output table. Given the huge workload, the accuracy of the data may be questionable. Second, the relevant literature only calculates implied carbon without analyzing the relationship between trade and carbon emissions. Thus, the research conclusions are not convincing.

The contribution of this study is as follows. (1) Few research studies on Sino-US trade liberalization and  $CO_2$  emissions are available at present. Our study investigates the effects of the Sino-US trade liberalization on the environment. And it is this manuscript's main innovation. (2) We also attempt to explore the influencing mechanism that how Sino-US trade liberalization affect  $CO_2$  emissions, which is seldom concerned in the previous literature.

## 3. Method and Data

3.1. Model and Variables. We adopt the following traditional OLS model to test the effects of the Sino-US trade liberalization on China's  $CO_2$  emissions:

$$\operatorname{Ln}(\operatorname{CO}_2)_{it} = \beta_0 + \beta_1 \operatorname{Ln}T_{it} + \beta_{\operatorname{control}_{it}} + \gamma_t + \eta_i + \varepsilon_{it}, \quad (1)$$

where CO<sub>2</sub> refers to CO<sub>2</sub> emissions, Ln is the natural logarithm,  $\beta_0$  refers to the constant term, *T* is the core explanatory variable of the Sino-US trade openness, control refers to other control variables, including economic growth, population, technology level, industrial structure, energy structure, transportation, and other variables, *i* represents the provincial section unit, *t* refers to the time,  $\eta_i$  represents the provincial fixed effect,  $\gamma_t$  represents the time effect, and  $\varepsilon$ stands for the error term.

 Carbon *Emissions (CO<sub>2</sub>)*. The explained variable is the natural log of carbon emissions in 27 provinces. Currently, no official statistical data on carbon emissions in China are available. CO<sub>2</sub> emissions are usually calculated in accordance with the following formula:

$$C = \Sigma E \times CF \times CC \times COF \times \left(\frac{44}{12}\right), \qquad (2)$$

where *C* refers to  $CO_2$  emissions estimated from fossil energy consumption, *E* refers to the energy consumption, CF is the net calorific value of various energies, CC is the carbon emission coefficient, and COF is the carbon oxidation factor. The carbon emission coefficient and the conversion coefficient are from IPCC (Intergovernmental Panel on Climate Change).

- (2) Sino-US Trade Liberalization (T). The core explanatory variable is the natural logarithm of the Sino-US trade liberalization in each province. We use foreign trade dependence (total import and export/GDP) to measure the Sino-US trade liberalization. We also consider the proportion of total import and export trade to the US in each province's GDP. We convert the total import and export trade volume to CNY at the annual average exchange rate. The data of import and export trade to the US in each province's GDP come from statistical yearbooks of various provinces.
- (3) Economic Growth (pgdp). We measure economic growth in terms of GDP per capita. We adopt a quadratic equation to test the EKC (Environmental Kuznets Curve) hypothesis and investigate the relationship between economic growth and carbon emissions. We convert GDP per capita into real value (last year = 100). The data of GDP per capita come from statistical yearbooks of various provinces.
- (4) Population Density (pop). Following the IPAT model, we use the population as the main factor affecting the environment. Following Shao et al. [40], considering the huge differences among provinces in population size and land area, scientific comparability would be lost if we use population size to measure population factors. Therefore, we adopt population density to measure the effects of population agglomeration on carbon emission. As populations gather, energy consumption will increase and CO<sub>2</sub> emissions will rise.
- (5) *Industrial Structure (sec)*. Carbon emission comes mainly from fossil energy combustion, and the secondary industry is undoubtedly the main source of carbon emission. Following Grossman and Krueger [41], we consider the industrial structure as a critical factor affecting the environment. China is in the accelerated stage of industrialization and urbanization. The combustion of fossil fuels in the industrial sector intensifies carbon emissions. We use the proportion of the added value of the secondary industry in each province's GDP to measure the effects of industrial structure on carbon emissions.
- (6) Technical Level (rd). Clean technology innovation is a significant method for reducing carbon emissions. Grossman and Krueger [41] proposed the decomposition formula of pollution emission. They determined that scale, technology, and structure are the three main factors affecting the environment, among which the technological effect reduces pollution emission. Subsequently, numerous studies find that the technological effect reduces environmental pollution emissions. From the perspective of technology input, we use the proportion of R&D expenditure in the GDP of each province as the proxy variable of technology level. In the path of green technology

progress, the higher the internal expenditure for R&D, the stronger the technological innovation ability. This situation is conducive to improving energy efficiency and achieving energy conservation and carbon reduction.

- (7) Energy Structure (es). Coal plays a dominant role in China's energy consumption structure. Although China has been committed to reducing coal consumption, coal still accounts for nearly 60% of China's energy consumption structure. Coal is highcarbon energy, and  $CO_2$  from coal combustion is the main source of carbon emissions in China. We introduce the energy structure (proportion of coal consumption in the total energy consumption) as a control variable in the model.
- (8) Transportation (car). The economy and the quality of living have grown in recent years. Thus, the use of private cars has gradually been popularized in largeand medium-sized cities in China. The consumption of gasoline and transportation carbon emissions are also accelerating. We use private car ownership to investigate the effects of transportation factors on carbon emissions.

*3.2. Data.* The panel data of 27 provinces in Mainland China from 1998 to 2018 come from the China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, China Economic Network Statistical Database, and statistical yearbooks of various provinces. We exclude Tibet, Inner Mongolia, Qinghai, and Guizhou from the sample because of the large number of missing data. We convert GDP per capita to real value (last year = 100) and the total import and export trade volume to CNY at the annual average exchange rate. Table 1 provides the descriptive statistics of each variable.

3.3. Endogeneity and Instrumental Variables. Endogeneity can be difficult to avoid in studies on the relationship between trade and the environment. Endogeneity is present in the effects of trade liberalization on carbon emissions. The sources of endogeneity include missing variables, reverse causality, and measurement error, among others. On the one hand, trade influences CO<sub>2</sub> emissions through scale, structural, and technological effects. On the other hand, environmental regulation is likely to affect trade volume and foreign trade structure to some extent. At the same time, Model (1) may have missing variables. The measurement error of macrodata in developing countries is a well-known problem. Therefore, finding the appropriate IV is a practical and feasible method to alleviate endogeneity. An IV should be correlated (strongly correlated with the endogenous variables of the Sino-US trade liberalization). It should also be exogenous (uncorrelated with the error term). We refer to the research of Dai et al. [42] and employ the CNY/USD exchange rate as the IV. As an important factor affecting the Sino-US trade, the exchange rate of CNY/USD changes the relative prices of import and export commodities. However,

Variable	Definition	Mean value	Standard deviation	Minimum value	Maximum value
CO <sub>2</sub>	Carbon emission (tons)	32297.78	25701.03	563.55	151958.6
Т	China-US trade liberalization	0.0565	0.0946	0.0005	0.621
Pgdp	Per-capita GDP (CNY/person)	31051.34	26046.22	3541.08	107217.1
Pop	Population density (person/km <sup>2</sup> )	2164.106	1430.861	2.4	6307.38
Sec	Proportion of the added value of the secondary industry in GDP (%)	45.82	8.08	18.63	61.5
Rd	Proportion of internal expenditure on R&D in GDP (%)	1.35	1.06	0.146	6.014
Es	Energy structure (%)	59.40	21.89	0.538	92.78
Car	Private car ownership (10,000)	230.88	317.76	2.1	1910.26

TABLE 1: Variable statistical description.

the CNY/USD exchange rate does not directly influence China's  $CO_2$  emissions and only affects the  $CO_2$  emissions by influencing trade. Therefore, the CNY/USD dollar exchange rate is appropriate as an IV in this study.

We form the first stage regression equation (2). This equation allows us to verify the effects of the exchange rate shocks on the Sino-US trade liberalization. In equation (2),  $\lambda$  represents the effects of the instrumental variable of the exchange rate on the Sino-US trade openness. An increase in the exchange rate means the depreciation of the RMB will lead to an increase in exports and a decrease in imports. We use the two-stage least squares (2SLS) method to estimate equations (1) and (2).

$$T_{it} = \beta_0 + \lambda \text{Exchange}_{it} + \theta Z_{it} + \gamma_t + \eta_i + \varepsilon_{it}.$$
 (3)

## 4. Results

4.1. Benchmark Regression. Our empirical research begins with OLS. Table 2 shows the results. Models (1)–(4) are the results of the fixed effects with more control variables. In Model (1), if the Sino-US trade openness has increased by 1%, China's carbon emissions will be reduced by 0.056%. In Model (2), more control variables are evident, and the coefficient of the Sino-US trade openness remains significantly negative. In Model (3), the coefficient of the Sino-US trade openness is -0.079 and significant. Model (4) has fixed the year effect on the basis of Model (3), and the coefficient of the core explanatory variable is -0.0696. Therefore, the benchmark regression shows that the Sino-US trade opening has reduced CO<sub>2</sub> emissions in China.

As for the control variables, the coefficients of population density in the four models are all positive but insignificant. The coefficient of GDP per capita is positive and the quadratic term is negative, which verifies the inverted U shape of EKC. In Models (3) and (4), the coefficient of sec is significantly positive, indicating that the structural effect is positive and the growth of the secondary industry intensifies  $CO_2$  emissions. The coefficient of energy consumption structure (es) is significantly positive, and the increase in coal consumption will undoubtedly promote the growth of  $CO_2$  emissions. The expansion of private car ownership increases car use and petrol burning, which also increases  $CO_2$  emissions.

4.2. *IV Estimation*. We analyze the effects of the Sino-US trade liberalization on environmental quality with the IV of the CNY/USD exchange rate by the 2SLS method. Table 3

shows the results. The results of the first stage report the effectiveness of the instrumental variables. From Models (1) to (4), the F value of the first stage is all greater than 10, thereby eliminating the weak IV. Given the collinearity of the year dummy variable and the variable of the exchange rate, we only control the province-fixed effect in the models.

The IV regression results of Models (1)–(4) show that the coefficients of the Sino-US trade openness on  $CO_2$  emissions are significantly negative. This finding is consistent with the previous results of the fixed effects. In Model (4), a 1% increase in the Sino-US trade openness can reduce  $CO_2$  emissions by 0.2368%. The coefficient of GDP per capita is significantly positive, whereas the quadratic term is significantly negative. This finding verifies the inverted U-shaped relationship between economic growth and environmental quality. That is, with the growth of wealth per capita, environmental quality first deteriorates and then improves. For every 1% increase in coal consumption,  $CO_2$  will increase by 0.818%. For every 1% increase in private car ownership,  $CO_2$  increases by 0.22%.

4.3. Robustness Test. We test the robustness of IV identification in Table 4 to determine the reliability of the 2SLS estimates. China's exports to the US account for a major proportion of the former's trade with the latter. It is far higher than its imports from the US. Therefore, we use export liberalization to the US (a province's exports to the US/GDP). We replace the trade liberalization for robustness. In the first stage regression results, F values are greater than 10, excluding the weak IV problem, as shown in Table 4. In the second stage of the regression, the coefficients of export openness to the US are significantly negative. The export liberalization to the US (Lnexport) has increased by 1% and  $CO_2$  emission has reduced by 0.152% as shown in Model (4). Hence, the results of the baseline regression further confirm that the Sino-US exports have slowed down China's CO<sub>2</sub> emissions. The coefficients of per-capita GDP are significantly positive, whereas the quadratic coefficients are significantly negative. This finding is consistent with the results of the benchmark regression and further confirms the shape of the inverted U-shaped EKC.

We also use  $SO_2$  as the explained variable for the robustness test. Table 5 shows the 2SLS test results using  $SO_2$  as the dependent variable. The coefficients of the IV in the first stage are significant. The *F* values are greater than 10. In the second stage of regression, the coefficients of LnT are

TABLE 2: Resu	ts of benchmar	k regression.
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	(1)	(2)	(3)	(4)	
Explanatory variables		Explained v	ariable LnCO <sub>2</sub>		
LnT	$-0.056^{*}$ (0.0296)	-0.0926** (0.0351)	$-0.079^{**}$ (0.0383)	$-0.0696^{**}$ (0.0257)	
Lnpop		0.00836 (0.025)	0.0125 (0.024)	0.0323 (0.0241)	
Lnpgdp		3.854*** (0.697)	2.05*** (0.6823)	0.832 (0.802)	
$(Lnpgdp)^2$		$-0.16^{***}$ (0.0343)	$-0.0822^{**}$ (0.0358)	-0.0515(0.0353)	
Lnsec			0.343* (0.18)	0.4616** (0.189)	
Lnrd			0.0582 (0.085)	0.0453 (0.104)	
Es			0.958** (0.354)	1.233*** (0.2623)	
Lncar			$0.146^{**}$ (0.064)	0.113 (0.074)	
Cons	9.202*** (0.133)	12.537*** (3.511)	5.2* (2.8973)	3.371 (4.415)	
$R^2$	0.2287	0.2974	0.5678	0.3151	
Province-fixed effect	Yes	Yes	Yes	Yes	
Year-fixed effect	Yes	No	No	Yes	
Observations	489	470	450	450	

\*\*\*\*, \*\*\*, and \* represent the significance level of 1%, 5%, and 10%, respectively.

#### TABLE 3: IV estimation results.

	(1)	(2)	(3)	(4)			
First stage regression	Explained variable LnT						
IV	0.001521** (0.00067)	0.0017** (0.00068)	0.00177*** (0.00065)	0.0018*** (0.0006563)			
exchange rate	,	· · · · ·	× ,	· · · · · · · · · · · · · · · · · · ·			
Other explanatory variables							
<i>F</i> value	15.20	16.37	17.33	17.55			
Second stage regression		Explained v	ariable LnCO <sub>2</sub>				
LnT	$-0.283^{*}$ (0.164)	-0.353** (0.167)	$-0.234^{*}$ (0.133)	$-0.2368^{*}$ (0.132)			
Lnpop	0.023 (0.021)	0.0124 (0.022)	0.0314 (0.0197)	0.0296 (0.0197)			
Lnpgdp	4.78*** (0.863)	4.65*** (1.154)	3.043*** (1.002)	3.155*** (0.990)			
$(Lnpgdp)^2$	-0.207*** (0.0435)	$-0.1955^{***}$ (0.0587)	$-0.141^{**}$ (0.0577)	$-0.14680^{***}$ (0.0571)			
Es		0.842*** (0.251)	0.839*** (0.196)	0.818*** (0.1965)			
Lnsec			0.247* (0.14)	0.222 (0.139)			
Lncar			0.239*** (0.074)	$0.222^{***}$ (0.074)			
Lnrd				0.058 (0.0394)			
Cons	$-17.72^{***}$ (4.982)	$-18.287^{***}$ (6.201)	-9.674** (4.635)	$-10.31^{**}$ (4.58)			
Observations	470	452	451	450			
Province-fixed effect	Yes	Yes	Yes	Yes			
Year-fixed effect	No	No	No	No			
Adjusted R <sup>2</sup>	0.928	0.954	0.959	0.961			

\*\*\*, \*\*, and \* represent the significance level of 1%, 5%, and 10%, respectively.

significantly negative in four models. When the explained variable is SO<sub>2</sub> emissions, the Sino-US trade liberalization also reduces SO<sub>2</sub> emissions. When the Sino-US trade liberalization increases by 1%, SO<sub>2</sub> emissions will decrease by approximately 3%. The test shows that the effects of trade liberalization on the reduction of CO<sub>2</sub> emissions remain following different CO<sub>2</sub> emissions. The Sino-US trade liberalization has a greater effect on the reduction of SO<sub>2</sub> than CO<sub>2</sub> emissions.

4.4. Discussion on Influencing Mechanism. The results show that the Sino-US trade liberalization has not turned China into a "pollution haven." Instead, the Sino-US trade has slowed down  $CO_2$  emissions in China. Then, through which channels can such emission reduction effect be achieved? We analyze the mechanism of the Sino-US trade liberalization

that affect carbon emissions. We use the perspectives of scale, structural, and technological effects of trade.

The scale effect means that free trade will increase production activities, thereby expanding the economic scale and increasing pollution. Technological effect means that countries introduce advanced technology through foreign trade, enjoy technological spillover brought about by trade, and introduce more advanced technology and equipment to reduce carbon emission and environmental pollution. The structural effect means that international trade affects the environment by affecting the industrial structure. If international trade directs the host country's resources to clean and green sectors, then structural effects have a positive effect on the environment. On the contrary, if international trade directs the host country's resources to sectors with high pollution and high emissions, then structural effects will worsen environmental quality.

	(1)	(2)	(3)	(4)			
First stage regression	Explained variable Lnexport						
IV exchange rate	0.00253*** (0.00069)	0.00258*** (0.00072)	0.00277*** (0.00068)	0.00281*** (0.00068)			
Other explanatory variables	_	_	_	_			
<i>F</i> value	13.43	12.74	16.49	16.84			
Second stage regression		Explained va	riable LnCO <sub>2</sub>				
Lnexport	$-0.1699^{*}$ (0.0907)	-0.235** (0.092)	-0.15** (0.0756)	$-0.152^{**}$ (0.075)			
Lnpop	0.015 (0.018)	0.00068 (0.018)	0.024 (0.0163)	0.0226 (0.0164)			
Lnpgdp	4.447*** (0.606)	3.99*** (0.709)	2.443*** (0.595)	2.548*** (0.59)			
$(Lnpgdp)^2$	$-0.19^{***}$ (0.0307)	$-0.161^{***}$ (0.036)	$-0.119^{***}$ (0.035)	$-0.114^{***}$ (0.0345)			
Es		1.23*** (0.15)	1.071*** (0.1385)	1.054*** (0.139)			
Lnsec			0.32*** (0.101)	0.297*** (0.102)			
Lncar			0.23*** (0.059)	0.214*** (0.0595)			
Lnrd				0.0536 (0.0373)			
Cons	-15.57*** (3.383)	$-14.97^{***}$ (3.857)	$-6.96^{**}$ (2.78)	$-17.72^{***}$ (4.982)			
Observations	470	452	451	450			
Province-fixed effect	Yes	Yes	Yes	Yes			
Year-fixed effect	No	No	No	No			
Adjusted $R^2$	0.9528	0.9598	0.9679	0.9679			

TABLE 4: Robustness test of changing the core explanatory variables.

\*\*\*, \*\*, and \* represent the significance level of 1%, 5%, and 10%, respectively.

TABLE 5	: Ro	bustness	test of	changing	the	explained	variable.
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	(1)	(2)	(3)	(4)			
First stage regression	Explained variable LnT						
IV exchange rate	0.00154** (0.000666)	0.00173** (0.00068)	0.00177*** (0.00066)	0.0018*** (0.0006568)			
Other explanatory variables	—	—	_	—			
F value	15.35	16.45	17.32	17.53			
Second stage regression		Explained v	variable LnSO <sub>2</sub>				
LnT	-3.772** (1.527)	-3.371*** (1.245)	-3.235*** (1.131)	$-3.176^{***}$ (1.1)			
Lnpop	0.398* (0.204)	0.3806** (0.1848)	0.46** (0.192)	0.465** (0.188)			
Lnpgdp	19.888** (8.565)	22.21** (8.867)	22.56** (8.835)	21.68** (8.59)			
$(Lnpgdp)^2$	$-1.037^{**}$ (0.431)	$-1.162^{**}$ (0.45)	$-1.355^{***}$ (0.512)	$-1.31^{***}$ (0.497)			
Es		-2.756 (1.72)	-2.057 (0.1385)	-1.94 (1.425)			
Lnsec			-2.043* (1.123)	$-1.907^{*}$ (1.1)			
Lncar			1.536** (0.685)	1.6** (0.679)			
Lnrd				-0.245(0.321)			
Cons	100.45** (48.79)	106.71** (47.567)	-92.64** (41.21)	-87.93** (40.15)			
Observations	473	454	453	452			
Province-fixed effect	Yes	Yes	Yes	Yes			
Year-fixed effect	No	No	No	No			
Adjusted R <sup>2</sup>	0.9682	0.9698	0.9775	0.9779			

\*\*\*, \*\*, and \* represent the significance level of 1%, 5%, and 10%, respectively.

The coefficients of per-capita GDP are positive, and the coefficients of the quadratic term are negative, which verifies the shape of the inverted U-shaped EKC, as shown in Tables 3–5. In other words, in the initial stage of China's development, growth deteriorates the environment. With the further increase in per-capita wealth and under the back-ground of environmental regulation and the improvement of people's awareness of environmental protection, growth alleviates environmental pollution. Therefore, in the context of China's pursuit of high-quality economic development, people's awareness of environmental protection is gradually increasing, and local governments' efforts to protect the environment become evident.

We calculate the turning point value of the inverted U-shaped curve and obtain the real per-capita GDP of the turning point of 46,166 CNY by letting the first-order differential of equation (4) in Table 3 to be zero. This method is close to the turning point calculated by Shao et al. [40]. The provinces that crossed the turning point and the years are given as follows: Guangdong (2011), Hubei (2014), Henan (2017), Jiangsu (2010), Zhejiang (2010), Anhui (2018), Fujian (2011), Jiangxi (2018), Shandong (2011), Hunan (2016), Hebei (2018), Sichuan (2018), Shaanxi (2014), Jilin (2016), Liaoning (2011), Shanghai (2004), Beijing (2006), Tianjin (2008), Chongqing (2015), Hainan (2017), Ningxia (2016), and Xinjiang (2018). Most provinces have already passed the

inflection point of the inverted U-shaped curve and are now in the downward trend of the EKC curve.  $CO_2$  emission declines with an increase in economic growth. At this stage of economic development, the scale effect produced by the Sino-US trade liberalization promotes economic growth. However, it does not necessarily lead to an increase in  $CO_2$  emissions.

The Statistical Yearbook of China's Foreign Trade reported that from the perspective of the China-US trade structure, China's exports to the US from 1998 to 2018 rank at the top in terms of the following commodity value: mechanical and electrical products, miscellaneous products, textiles and raw materials, base metals and products, transportation equipment, plastics, rubber, shoes, hats, umbrellas, and other light industrial products. Among them, mechanical and electrical products account for nearly half of China's total exports to the US. Thus, mechanical and electrical products are the country's most important exports to the US. Exports of sundry goods, textiles and raw materials, and base metals and products also increased from 1998 to 2018, that is, with sundry goods accounting for 11% of China's exports to the US, textiles and raw materials for 9%, and base metals and products for 5% in 2017 and 2018. Therefore, China's exports to the US are concentrated in two categories: technologyintensive commodities (such as mechanical and electrical commodities) and labor-intensive goods (such as textiles, metal products, and other light industrial products). They are low-pollution and low-emission products. Therefore, we find that the Sino-US trade does not introduce resources into pollution-intensive industries in China. On the contrary, the structure of Sino-US trade is of low-carbon. Therefore, the structural effect of the Sino-US trade is positive and does not burden the environment.

Scholars agreed that the technological effects of trade can reduce pollution emissions [12, 32, 43–48]. Technological effects of trade mean that host countries can introduce advanced technology through foreign trade and enjoy technology spillover advantage by FDI, thereby decreasing carbon emissions. First, lax environmental restrictions in host counties might attract more advanced technologies. Usually, advanced technologies are cleaner than traditional ones due to the improvement of environmental awareness globally. Second, trade openness has improved the income of trade partners. People pursue to have a cleaner environment after becoming rich. Therefore, more strict pollution restrictions become people's environmental requests after economic growth [41].

On the basis of the above analysis, the opening up of trade between China and the US, which is driven by the scale, structural, and technological effects, has slowed down China's  $CO_2$  emissions. The Sino-US trade liberalization has increased by 1% and  $CO_2$  emissions have reduced by 0.2368%. The Sino-US export liberalization has increased by 1% and  $CO_2$  emissions have reduced by 0.152%.

# 5. Conclusion and Future Works on Fractional Phenomenon

How does free trade between China and the US causally affect  $CO_2$  emissions? The existing literature on the Sino-US trade liberalization and  $CO_2$  emissions focuses on implied

carbon. In the current study, we use the panel data of CO<sub>2</sub> emissions of 27 provinces in China from 1998 to 2018 to examine the effects of the Sino-US trade liberalization on CO<sub>2</sub> emissions and its mechanism. We employ the CNY/ USD exchange rate as the IV for identification. The main conclusions are as follows. (1) The Sino-US trade liberalization has a positive effect on the environment. It reduces CO2 emissions. A1% increase in the Sino-US trade openness can reduce CO<sub>2</sub> emissions by 0.2368%. (2) The scale effects produced by the Sino-US trade liberalization have boosted economic growth without driving a surge in CO<sub>2</sub> emissions. China's exports to the US are mainly technology-intensive and labor-intensive products, and it should be low carbon of the structure effect of the Sino-US trade liberalization. The technological effects of trade are good for the environment. The opening up of trade between China and the US has slowed down the former's CO<sub>2</sub> emissions due to the combination of scale, structural, and technological effects. (3) An inverted U-shaped relationship between economic growth and environmental quality is evident in China. The real percapita GDP of the turning point is 46,166 CNY. A total of 22 provinces and municipalities have already crossed the inflection point of the inverted U-shaped curve and are in the downward range of the inverted U-shaped curve.

Due to data availability, we adopted only  $CO_2$  and  $SO_2$  to represent pollution while these two indicators reflected only part of environmental quality, which needs to be extended in the future.

The policy implications are definite. As an engine of economic growth, international trade has undoubtedly promoted globalization and accelerated China's deep participation in the global supply chain. It has ultimately achieved rapid economic growth and improved welfare. The US is one of China's most important trading partners. Trade liberalization with the US has reduced  $CO_2$  emissions. Therefore, from the perspective of China's interests and the angles of growth and environmental protection, China should be committed to promoting trade liberalization. The government should exert every means to avoid trade wars and further promote globalization to achieve a win-win situation between growth and environmental protection.

Based on the previous research and the judgment of the future development trend, this paper believes that due to the great advantage of nonlocality, the fractional phenomenon can be used as an important development direction of related research in the future. In this paper, with the help of the tool of the fractional phenomenon, we make the following prospects in the future.

Compared with integer order, the nonlocality of fractional order can be used to solve the related problems of systems with memory effect. As far as the research content of this paper is concerned, many variables that affect the environment, such as the concentration of existing pollutants, have the characteristics of long-term timeliness. They may make the behavior of the system present a state similar to random, and the nature of this state cannot be revealed by using the traditional theory alone, so it is necessary to introduce the fractional phenomenon to explain it. It can make the explanation of the influencing factors of environmental problems more comprehensive, not only considering the impact of the main data indicators on the environment in the research period but also involving the lag effect of the original data.

Second, an important role of the fractional phenomenon is to predict the future results. Because it can accurately describe the memory and genetic properties of a certain process, the prediction of complex events with the help of the fractional phenomenon is more accurate and reliable than that with simple linear regression. At present, the literature has used fractional order to predict air pollution and other related problems. In addition, the fractional-order grey prediction model constructed by fractional order has another important advantage; that is, it can be regarded as a grey system when there is a lot of system information that cannot be measured or obtained, and the prediction is made to solve the problem that cannot be studied due to data unavailability. In the case that some enterprises or industries are unwilling to disclose the pollution data for various reasons, it is a solution to forecast the future pollution with the help of the fractional grey prediction model.

# **Data Availability**

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## **Conflicts of Interest**

The authors declare that they have no conflicts of interest.

### **Authors' Contributions**

Yanchun Yi designed this study and participated in all phases; Yaqing Li contributed analysis tools. All authors read and approved the final manuscript.

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