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How Does Green Trade Affect the Environment? Evidence from China

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ABSTRACT

This study focuses on the impact of trade in environmental goods (green trade) on the environment. We found that green trade can decrease pollution levels by exploiting a panel of 277 Chinese cities from 2004 to 2013 and using the instrumental variable (IV) strategy. However, total trade openness is far less favorable to the environment. We also found that both green imports and exports are conducive to the Chinese environment, while ordinary green trade performs better than green processing trade. Nevertheless, the effects of green trade are restricted by a city's purchasing power and absorptive capacity, as well as the classifications of environmental goods. Furthermore, green trade mainly promotes local green technological progress to benefit the environment.

KEYWORDS

Green trade; Environmental pollution; Green imports; Green exports; Instrumental variable

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1. Introduction

China has realized astonishing economic growth in recent years, which, however, has heavily depended on extensive investment and has come at the expense of environmental quality. China is starting to play an increasingly positive role in climate-change negotiations and has designed numerous policies to deal with pollution issues. Specifically, China has devoted itself to building the capacity for green technology and renewable energy. The five concepts of innovation, coordination, green, openness, and sharing proposed at the Fifth Session of the 18th National Congress of the Communist Party of China have served as new strategic guidelines for China to tackle development issues and foster long-term advantages. Among them, the concept of green focuses on solving the problem of harmony between humans and nature, while openness focuses on solving the problem of linking internal development and external development. Naturally, green trade based on Environmental Goods and Services (EGS)[1] has become the joint point of green and openness. In 2001, the WTO also advocated for reducing or eliminating trade barriers on EGS and maintained that the trade liberalization of EGS could coordinate the relationship between economic growth and environmental protection.

Similar to the overall total trade surplus, China has been showing a trade surplus in both imports and exports of environmental goods (EGs) since the 21st century. The market size of China's EGS reached USD 6.07 billion in 2016, with an average annual increase of 12% since 2004, making it the fastest-growing market in the world (China's Green Trade Development Report, 2017). As a new strategic industry, the eco-industry has also entered a new historical development period in China. Meanwhile, China is actively participating in global governance and shouldering international responsibilities. For instance, in 2009, China promised to cut carbon emissions per unit of GDP by 40% to 50% by 2020 compared to 2005 levels at the Copenhagen Climate Conference. Behind this international commitment is China's efforts to accelerate green and low-carbon transformation. Against this backdrop, we are curious about whether China's trade boom in EGs is conducive to its environmental goals and what we can learn from the experience of this enormous developing economy.

To answer the above question, this study investigates the impact of trade in EGs (also referred to as green trade in the following text) on environmental quality based on unique panel data from 277 Chinese cities from 2004-2013. Our findings support the environmental benefits produced by improved access to EGs. Specifically, green trade (both imports and exports) can explain the drop in Chinese pollution intensity, while ordinary trade in EGs behaves better than processing trade in EGs. Moreover, a city's purchasing power and absorptive capacity, along with the classifications of EGs, can influence the environmental effects of green trade. The results also show that green trade is beneficial as it helps upgrade environmentally sound technologies (EST).

The potential contributions of this study are threefold: (1) we expanded the trade and pollution research by investigating the effect of an emerging group of traded products - the EGs - that are expected to affect emissions, combining trade, the environment directly, and technology innovatively; (2) with the paucity of direct green trade data in China, we constructed a particular city-level panel dataset for empirical analysis. Our results may offer insights into the adjustment of environmental policies, trade policies, and other development policies not only for the Chinese government but also for other developing country stakeholders who have an interest in encouraging the transition to a greener economy; (3) the endogeneity problem is expected in the empirical literature concerning trade and growth, and we employed an instrumental variable (IV) strategy to deal with this issue.

The remainder of the article is structured as follows. Section 2 presents the theoretical framework. Section 3 describes the methodology and data. Section 4 presents the empirical results, and the final section states the conclusions and policy implications.

[1] OECD (1999) defined EGS as goods and services to measure, prevent, limit, minimize, or correct environmental damage to water, air, and soil, as well as problems related to waste, noise, and ecosystems.

2. Theoretical framework

2.1. Definition of green trade

As aforementioned, green trade in this paper refers to trade in EGs. The concept of EGs covers all products related to environmental issues, but there has been no universally accepted definition of EGs.

The United Nations Conference on Trade and Development (UNCTAD) has identified two types (Class A and Class B) of EGs for analytical purposes based on the definitions of the OECD and APEC, which are the most discussed and commonly accepted types under the Doha Round negotiations. Based on their lists, our principal empirical analysis focuses on (1) Class A EGs, which incorporate all industrial goods for providing environmental services, and (2) Class B EGs, whose production, end-use, and disposal are more environmentally friendly compared to their substitutes and complements, along with (3) Class C EGs, which is drawn from the list in Trade in Environmentally Sound Technologies: Implications for Developing Countries[2], co-published by the United Nations Environment Programme (UN Environment), the University of Oxford, and the Norwegian University of Science and Technology. All the EGs mentioned above are identified according to the Harmonized System (HS) subheadings (see Appendix A).

2.2. Literature review

There are no conclusive results regarding trade and environment cases, and the related disputes are still rising (Sampson, 2000). For example, Brunnermeier and Levinson (2004), Copeland and Taylor (2004), Levinson (2008), Millimet and Roy (2012), Elliott and Zhou (2013), and Cherniwchan et al. (2017) discuss pollution haven, pollution halo, race-to-the-bottom/top, etc.

Classically, these three effects of trade on the environment have been proposed by Grossman and Krueger (1993), Copeland and Taylor (1994), and Taylor and Copeland (2001). Specifically, the scale effect illustrates that the expanded economic activity brought by international trade can increase environmental issues. The composition effect suggests that international trade may influence the environment by changing the structure of trade and thus production, which may lead to the pollution haven problem. That is to say, highly pollutive industries may relocate to countries or regions that have loose environmental regulations. Additionally, countries or regions may be unwilling to tighten regulation policies concerning international competitiveness and economic growth. The technique effect indicates that international trade makes countries or regions more accessible to environmental technologies and practices, as well as advanced international demands and quality requirements, which may promote their green technical progress.

Generally, the directions of the scale effect and technique effect are opposite, whereas the composition effect relies on countries or regions' comparative advantage and regulation level. As a consequence, the net impact of trade on the environment will be uncertain and requires detailed empirical tests (Tamiotti, 2009). The empirical literature remains ambiguous. Antweiler et al. (1998) showed that expanded trade might worsen environmental conditions. Ederington et al. (2004) and Martin (2011) suggested that changes in pollution are unaffected by tariff changes. Antweiler et al. (2001) found that trade may benefit the environment subject to countries' comparative advantage, but their study identifies the issue of unobserved shocks. Frankel and Rose (2005) employed a different identification method, the geography-based IV approach, suggesting that trade decreases emissions once income is controlled.

Put slightly differently, Yu (2007) claimed that trade liberalization of EGs would bring a chance to realize a triple-win relationship between trade, the environment, and development. The reasons are that (1) trade in EGs

[2] http://www.greengrowthknowledge.org/resource/trade-environmentally-sound-technologies-implications-developing-countries.

lowers the costs of environmental technologies and allows for further technology transfers, (2) new job opportunities and the boost in industrial and exporting capacities of EGs will stimulate further economic growth. Nimubona (2012) proclaimed that the environmental benefits of trade in EGs are achieved by sacrificing social welfare, for which governments may compensate. Although the green trade topic is gaining increasing attention in the research community, empirical studies on the impact of pollution on trade in EGs are still deficient. Alwis (2015) argued that trade in EGs could decrease S02 emissions, which would be observed more in capital-abundant countries. Zugravu-Soilita (2018) explored how the effects of trade intensity on air pollution of EGs are offset by the beneficial outcomes regarding regulatory degrees and income improvement.

Regarding studies on trade and the environment in China, we have only noticed a few, and more importantly, none of them have the same focus as ours. Dean (2002) investigated the relationship between trade and water pollution with national-level indicators of trade openness in China and pure time-series data, while our study utilizes a panel dataset. De Sousa et al. (2015) used city-level export data but focused on how processing trade affects pollution levels in China. Studies like Lin et al. (2014) and Zhao et al. (2010) have investigated how China's trade influences different pollutants from a global view.

From the brief literature review above, we have summarized that (1) the majority of studies on trade and pollution ignore the features of the products traded; (2) some studies emphasize the importance of green trade but fail to offer sufficient empirical evidence, especially in developing countries; (3) there are no Chinese cities, in particular, reporting green trade statistics every year, thus leaving gaps in related research. This study takes a step further by exploring the relationship empirically between green trade and environmental pollution in the context of China to address the above gaps.

3. Methodology

This section lays out our empirical methodology and builds the empirical measures that capture our main variables.

3.1. Model specification

We aimed to assess how green trade affects pollution in individual cities in China, so we set up the basic model as follows.

$$P_{it} = c_1 + \alpha_1 GT_{it-1} + \alpha_2 S_{it} + \alpha_3 S_{it}^2 + \alpha_4 \sum X_{it} + \epsilon_i + \tau_t + \varepsilon_{it} \quad (1)$$

where i represents city and t represents year. The explained variable, P_{it}, refers to the general environmental pollution index in city i at time t. The explanatory variable, GT_{it-1}, denotes the green trade proportion. We lagged the main explanatory variables for a period to reduce the possibility of reverse causality. Parameter α_1 is our main interest. A negative sign of α_1 indicates that green trade decreases the pollution level. The terms of S_{it} and S_{it}^2 reflect the effects of income on emissions. Several studies have found that per capita income level and environmental pollution have a nonlinear negative U-shaped relationship (e.g., Shafik, 1994; Grossman and Krueger, 1995; Cole, 2003), i.e., Environmental Kuznets Curve (EKC). We included income squared here to verify EKC. The parameter $\sum X_{it}$ is a matrix of other control variables. The parameter ϵ_i is the city-fixed effect. The parameter τ_t is the year-fixed effect. The parameter ε_{it} denotes the stochastic error term.

3.2. Data

Our dataset covers 277 prefecture-level cities from 2004 to 2013 and mainly includes two parts, i.e., trade data and city characteristics data. Trade data for this study were collected from China Customs, which contains detailed information on each international trade transaction of Chinese firms. Other city-level data are mainly drawn from the CEIC database, EPS database, and Urban Statistical Yearbook. We supplemented the above dataset by manually gathering information from provincial statistical yearbooks and government reports. Hereafter, we explain how each variable was measured. Appendix C also offers a summary table of all the variables.

3.2.1. Explained variable

Environmental pollution (P). Wastewater, waste gas, and solid waste (industrial "three wastes") are the three significant types of pollution as by-products of industrial production. We collected data on industrial three wastes and PM2.5 and employed the entropy method to calculate a comprehensive index proxying environmental pollution. We used the air pollution grid data jointly released by Columbia University and the American Atmospheric Composition Group to extract the annual PM2.5 average emission concentration of cities in China using ArcGIS software.

The calculation steps are as follows. First, we standardized the above emissions data.

$$\gamma_{ij} = \frac{x_{ij} - x_{\min(j)}}{x_{\max(j)} - x_{\min(j)}} \tag{2}$$

where i is the year and j represents the kind of emissions. The parameter x_{ij} is the ratio of emission j to local GDP at time t. The parameter $x_{\max(j)}$ and the parameter $x_{\min(j)}$ is the maximum and minimum of the index, respectively. The parameter γ_{ij} represents the value after standardization.

Second, we calculated the entropy value. There are m samples and n emissions index in this study. The parameter w_j is the entropy value of emission j.

$$f_{ij} = \frac{\gamma_{ij}}{\sum_{i=1}^{m} \gamma_{ij}} \tag{3}$$

$$k = \frac{1}{lnm} \tag{4}$$

$$h_j = -k \sum_{i=1}^{m} f_{ij} ln\, f_{ij};\ 0 \leq\ h_j \leq 1 \tag{5}$$

$$w_j = \frac{1 - h_j}{\sum_{j=1}^{n} (1 - h_j)};\ \left(0 \leq\ w_j \leq 1, \sum_{i=1}^{m} w_j = 1\right) \tag{6}$$

Finally, we used w_j as a weight to obtain the general index of environmental pollution.

$$p_{ij} = \sum_{j=1}^{n} x_{ij} w_j \tag{7}$$

3.2.2. Explanatory variable

Green trade (GT) refers to the trade ratio of EGs to total trade, i.e., the proportion of green trade. Given that local statistical bureaus in China do not directly provide trade data on specific products, we summed up the transaction data in the China Customs Database at the city level as an alternative method. We processed the original data as follows: First, we aggregated the customs data annually according to the HS 6-digit code, import and export mode, and trade mode (including processing trade and ordinary trade). Second, we grouped the data to the level of prefecture-level cities year by year based on the database's code structure of import and export enterprises. The top five digits of the enterprise code[3].

Total Trade (TT) denotes the total trade intensity, measured as the proportion of the total trade value to local GDP. We also checked the effects of overall trade openness for comparison.

3.2.3. Control variables

Real GDP per capita (S). Since there is no direct per capita income data, we use per capita gross domestic product (GDP) instead. Real means that we have taken 2003 as the base period to deflate the index.

Regulation (Reg) refers to pollution control levels. We used each city's utilization rate of solid waste as a proxy.

Industrial structure (Str) is the proportion of the value of the second industry to regional GDP, reflecting the level of industrialization.

The degree of government intervention (Gov) is indicated by government size and measured as the proportion of government budget expenditures to GDP.

Foreign direct investment (FDI) is proxied by the ratio of FDI to regional GDP.

Capital-labor ratio (K/L). Labor is measured by the number of employees in each city. Capital is calculated using the Perpetual Inventory System (Zhang et al., 2004). Specifically, we used the total fixed assets investment in 2003 as a numerator divided by the sum of the depreciation rate and the average growth rate of fixed assets investment in 2004-2013 to evaluate the capital stock in 2004 by the following equation.

$$K_{it} = K_{it-1}(1-\delta_t) + I_{it} \tag{8}$$

where K_{it} refers to the capital stock in city i at time t; subscript refers to the capital stock in city i at time t-1; I_{it} refers to investment in fixed assets of city i at time t, which is adjusted to the constant price based on 2003 by using fixed-asset investment indices. The parameter δ_t is the discount rate at time t, which is 10.96% in this study (Shan, 2008).

Human capital (Edu) is proxied by age-relevant education attainment information for cities. We set primary school as six years, junior high school as nine years, senior high school as twelve years, and college or above as 16 years, then the average length of education in the city equals $6S_1 + 9S_2 + 12S_3 + 16S_4$, where S_1, S_2, S_3, and S_4 represent the proportion of the population at each level of education in the total population.

Energy consumption (E). We used each city's annual electricity consumption as the level of energy consumption, taking the method of Qin (2014) for reference.

Population density (Dens) is the ratio of population to land area.

3.3. Endogeneity and IV strategy

The basic model may have several econometric problems. First, even though we have employed the lagged term of the trade index to circumvent the two-way causality, there may exist other unobserved variables that affect trade and pollution simultaneously. For instance, according to studies on the environmental Kuznets curve, income level will positively affect the ecological quality (i.e., high income can bring about the government's stricter environmental policies and improve consumers' willingness to pay for EGS). The second concern is related to the fact that some of the variables might be measured with an unexpected error. The third issue is related to omitted variables. Hence, this study used the IV method to address the endogeneity problems.

An influential IV must satisfy two fundamental principles: relevance and exclusiveness. Referring to existing literature, this study constructs two IVs for green trade proportion and total trade intensity, respectively, based on

[3] The first and second digits refer to provinces, the third and fourth digits indicate provincial municipalities, including provincial capital cities planned separate cities, and coastal open cities, and the fifth is the code of the economic zone of provincial municipalities.

the geographical characteristics of each city - Foreign Market Access (FMA). Geographical distance does not directly affect environmental indicators but plays a part via trade indicators. Moreover, environmental pollution does not change the geographical characteristics of cities. In the existing trade literature, there are two main geographic characteristic variables: the distance from the city to the port (Huang et al., 2014) and the distance to the coastline (Huang & Li, 2006). This study chooses the closest distance from cities to three ports (Hong Kong, Shanghai, and Tianjin, critical maritime hubs in China) as the IV. Since geographic distance does not shift with time, to include the dynamic features, we made the following adjustments as well:

(1) Similar to Yu et al. (2019), we also chose the ratio of global green trade to adjust, which can more accurately reflect the time-varying IVs. Therefore, the ultimate IV for green trade proportion used in this paper is the cross term between the shortest distance described above and the proportion of global green trade (FMA*GGT).

(2) Referring to the method of Acemoglu et al. (2005), we multiplied FMA by time dummy variables and obtained ten new variables, namely FMA* Y2004, FMA* Y2005, and so on. These ten variables are combined as IVs for total trade intensity.

The geographical distance data is calculated using ArcGIS, while the global trade flow data is drawn from the Comtrade database.

3.4. Description of trade and pollution

In this section, we will briefly describe the data of interest. Fig. 1a indicates the total trade intensity of each city, showing that the eastern region of China has a high level of openness.

Figure 1-a. Total trade in China.

Fig. 1b shows the trade volume of environmental products in China. Most of the more developed provinces and cities in the trade of environmental products are in the eastern coastal developed areas, western Sichuan and Chongqing, and northeastern Liaoning Province are also among the top. We can see that the green trade proportion of each region shows a quite different pattern from the total trade intensity. Higher openness does not necessarily correspond to a higher proportion of green trade. For instance, lower total trade intensity but a higher green trade proportion is observed in numerous cities in Sichuan Province and Chongqing Province. This distribution is the result of original policies and efforts to foster the environmental protection industry. Being a strategic emerging industry, the environmental industry has formed an emerging industrial cluster, strong supporting serviceability, and many leading businesses in the two provinces after rapid development in recent years.

Fig. 1c depicts the pollution level and shows the central pollution zone in Beijing, Tianjin, Hebei, and so on. Besides, we can also see that the higher the proportion of green trade in a particular area, the lighter the pollution is. However, more rigorous empirical evidence is needed to support this observation.

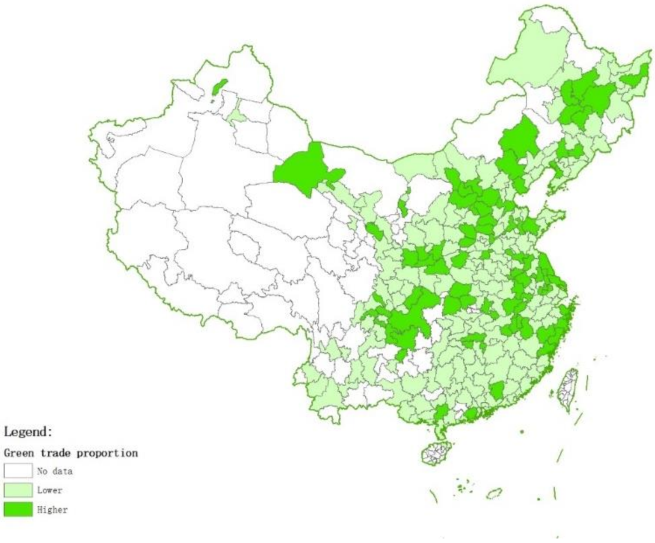

Figure 1-b. Green trade in China.

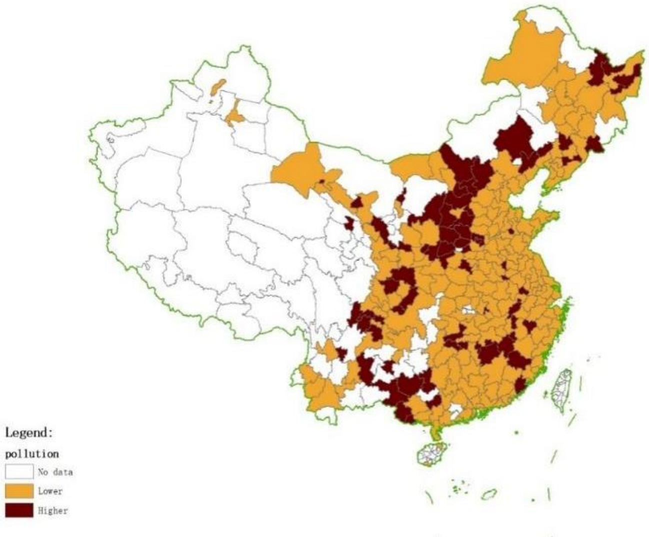

Figure 1-c. Pollution in China.

Source: generated by the authors using ArcGis software

4. Results

4.1. Basic results

Table 1 reports the results of the effects of green trade and total trade on pollution levels in China. Models 1–2 are pooled OLS specifications, whereas models 3–4 are estimated using a two-stage least squares (2SLS) procedure. The significance of some control variables increases in the 2SLS estimates, indicating that the overall regression results of the IV strategy are better.

We find a negative effect of green trade on pollution based on models 1 and 3. Using IVs dramatically increases the coefficient's magnitude due to the bias of OLS and the different core explanatory variables (lagged term in Model 1 while non-lagged term in Model 3). The correlation between IV and green trade is negative at the significance level of 10% in Model 3, which satisfies the hypothesis of relevance. The instrument is not weak in the first stage, as indicated by the value in brackets of 6.8 for the F-statistic in the first stage. Overall, trade in EGs has a negative environmental impact, which justifies our expectations. Among the control variables, we find no support for the Kuznets curve in the context of China. The pollution control level, government intervention, foreign direct investment, and population density will curb polluting activities during a specific year, while the level of industrialization and energy consumption has positive effects on environmental pollution.

Table 1. Environmental impact of green trade and total trade.

	(1) *P*	(2) *P*	(3) *P*	(4) *P*
L.GT	-0.0748**(-2.31)			
L.TT		-0.0191(-1.39)		
GT			-2.7093*(-1.69)	
TT				0.0159***(3.23)
S	-14.3051(-1.34)	-10.8548(-0.92)	13.9248(0.79)	-3.5863(-0.79)
S^2	0.2488(0.40)	0.0830(0.12)	-0.8782(-1.00)	-0.0620(-0.26)
Reg	-0.0270*(-1.70)	-0.0291*(-1.74)	-0.0938***(-2.81)	-0.0616***(-6.93)
Str	-0.0374(-0.66)	-0.0386(-0.66)	0.2710***(3.62)	0.1746***(7.74)
FDI	-0.1892*(-1.80)	-0.1793*(-1.65)	-0.2691*(-1.96)	-0.2190***(-4.35)
GOV	-0.0348(-0.48)	-0.0357(-0.48)	-0.1915*(-1.68)	-0.0561***(-2.60)
K/L	-0.9891(-0.88)	-0.9503(-0.84)	0.6689(0.88)	-0.1362(-0.75)
Edu	1.3591(0.91)	1.3689(0.93)	1.7890(1.12)	0.6874(1.48)
E	0.0602(1.36)	0.0673(1.44)	0.1715**(2.11)	0.2419***(8.10)
Dens	-0.2313(-0.76)	-0.1805(-0.57)	0.0569(0.08)	-0.9419***(-4.26)
Fixed effect	Yes	Yes	Yes	Yes
N	2493	2493	2630	2630
Adj R^2	0.4142	0.4134		
First-stage			6.3014*(1.81)	
F-statistic			[6.38]	[125.60]
IV			*FMA* GGT*	*FMA* Year*

*Notes: t statistics are in parentheses; robust standard errors are clustered at the city level; * p < 0.1, ** p < 0.05, *** p < 0.01.*

In Model 2, total trade does not have a significant effect on the environment, while the IV estimations show that total trade openness tends to have a significant effect on pollution. Therefore, increasing total trade intensity leads to more emissions in China. This result supports the bottom-line race hypothesis (Esty & Dua, 1997; Esty & Gentry, 1997). As a consequence of trade liberalization, countries may lower their regulatory criteria to maintain or improve competitiveness (composition effect dominates), resulting in the so-called bottom-line race or even deterioration of the environment.

In conclusion, trade in EGs appears to help combat pollution issues, while total trade can harm the environment.

4.2. Extended results

This subsection extends our empirical analysis by considering different directions of trade flows, different modes of trade, and alternative classifications of EGs.

First, since China both imports and exports EGs and these have different working channels, analyzing the separate effects of EG imports and exports may provide us with richer insights. Thus, we repeated models (1) and (2) in Table 1 by substituting the explanatory variables with green imports (GIM, imports of EGs/total imports) and green exports (GEX, exports of EGs/total exports), respectively. Table 2 displays the estimation results. The lagged terms for the two variables are statistically significant with a negative sign, indicating that green imports and green exports are both beneficial for the environment in China. For imports of EGs, green products (as inputs or final products) may phase out brown products, decreasing emissions.

Moreover, polluting firms as importers of EGs will have more opportunities for cleaner production due to spillover effects. For exports of EGs, even though the production process of particular EGs may be pollutive, countries that enjoy more export opportunities from trade liberalization of EGs may also witness a decrease in pollution indicators. The reason is that EG exporters can benefit from an increased economic level driven by production and export activities related to EG industries. A higher income may induce more green innovations and enhance demand for cleaner goods. Additionally, EG exporters in developing countries often face stricter environmental scrutiny and product specifications from customers in developed countries.

Secondly, it should be noted that processing trade is the dominant trade mode in China, accounting for about half of the growth of exports and imports in China. Differences exist between the environmental effects of green processing trade and ordinary green trade. We subsequently investigate their impacts separately. For the core explanatory variable, models 3–4 in Table 2 are green processing trade (GPT, processing trade in EGs/total processing trade) and ordinary green trade (GOT, ordinary trade in EGs/total ordinary trade), respectively. No significant effect is found for processing trade in EGs, while ordinary green trade seems to be more effective in curbing polluting activities. The authors discuss the potential role of corporate efficiency differences in explaining these results. Compared with ordinary trade firms, processing trade firms are less efficient (Dai et al., 2011). Enterprises with higher efficiency are more likely to use environmentally sound technologies, making them more environmentally friendly (Cui et al., 2012).

4.3. Heterogeneous analysis

In this subsection, we explore how the effects of green trade on environmental pollution differ concerning cities' characteristics, with purchasing power indicated by financial convenience (the development of the financial market) and absorptive capacity indicated by general innovation capability (technological readiness).

Table 2. shows the environmental impact of imports and exports, processing trade, and ordinary trade of EGs.

	(1) *P*	(2) *P*	(3) *P*	(4) *P*
L.GIM	-0.0283**(-2.01)			
L.GEX		-0.0668*(-1.85)		
L.GPT			-0.0247(-0.92)	
L.GOT				-0.0587**(-2.02)
S	-14.2622(-1.32)	-14.3483(-1.34)	-14.0822(-1.30)	-14.1777(-1.32)
S^2	0.2542(0.41)	0.2393(0.39)	0.2328(0.37)	0.2369(0.38)
Reg	-0.0279*(-1.69)	-0.0275*(-1.69)	-0.0283*(-1.71)	-0.0275*(-1.70)
Str	-0.0328(-0.58)	-0.0367(-0.65)	-0.0354(-0.61)	-0.0365(-0.64)
FDI	-0.1954*(-1.86)	-0.1861*(-1.76)	-0.1823*(-1.71)	-0.1924*(-1.82)
GOV	-0.0295(-0.40)	-0.0351(-0.48)	-0.0326(-0.45)	-0.0355(-0.48)
K/L	-0.9471(-0.82)	-1.0753(-0.98)	-1.0514(-0.95)	-1.0011(-0.89)
Edu	1.3973(0.94)	1.4624(0.98)	1.4178(0.95)	1.3866(0.92)
E	0.0622(1.38)	0.0640(1.43)	0.0605(1.35)	0.0616(1.38)
Dens	-0.2241(-0.73)	-0.2482(-0.80)	-0.2170(-0.72)	-0.2374(-0.77)
City-fixed effect	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
N	2493	2493	2493	2493
Adj R^2	0.4139	0.4140	0.4134	0.4139

*Notes: t statistics are in parentheses; robust standard errors are clustered at the city level; * p < 0.1, ** p < 0.05, *** p < 0.01.*

First, China's green trade development faces an important issue: trade financing, especially for small and medium-sized private firms. The financing channels of eco-firms are not perfect enough because the banking system is inefficient. We run a regression on the interaction of the purchasing power variable (Fin) and green trade, with the result shown in the first column of Table 3. We can conclude that better access to finance makes the environmental effect of green trade greater. The availability of financial institutions is essential for creating new markets for EGS.

Second, technological readiness refers to the ability to adapt to existing technical knowledge. Cohen and Levinthal (1989) argued that internal scientific research and development might serve to absorb and modify external technologies. Morsink et al. (2011) believed that sufficient technological abilities are required to advance the deployment of green technologies worldwide. Generally, technological readiness is proxied by R&D intensity, but R&D spending data has only finite availability and is confronted with some measurement problems in China, so we used the total granted patent data (Abs) from the previous period as the proxy for current technological readiness (absorptive capacity) and ran a test for the interaction of absorptive capacity and green trade. The estimation model underlines similar findings: the general research conditions for innovation strengthen the environmental effect of green trade.

Finally, we estimated additional results on the following different EGs classifications, Class B (as GT2) and Class C (as GT3) defined in the previous text. As reported in Table 3, the estimates show insignificant effects of trade in EGs belonging to Class B or Class C. Based on these results, one can conjecture that the classifications of EGs restrict the impact of green trade on the environment to a certain extent. This again reflects that there indeed exist considerable troubles in defining EGs.

Table 3. Heterogeneous analysis.

	(1) *P*	(2) *P*	(3) *P*	(4) *P*
*Fin*L.GT*	-0.0176**(-2.09)			
*Abs*L.GT*		-0.0164**(-2.43)		
L.GT2			-0.0377(-0.96)	
L.GT3				-0.0194(-0.56)
S	-14.7530(-1.38)	-15.1175(-1.42)	-14.1846(-1.31)	-14.2347(-1.32)
S^2	0.2638(0.43)	0.2741(0.45)	0.2464(0.39)	0.2462(0.39)
Reg	-0.0271*(-1.70)	-0.0272*(-1.70)	-0.0281*(-1.70)	-0.0284*(-1.71)
Str	-0.0366(-0.64)	-0.0355(-0.62)	-0.0397(-0.69)	-0.0357(-0.62)
FDI	-0.1898*(-1.80)	-0.1945*(-1.88)	-0.1872*(-1.75)	-0.1883*(-1.75)
GOV	-0.0345(-0.47)	-0.0368(-0.50)	-0.0334(-0.45)	-0.0309(-0.42)
K/L	-0.9813(-0.87)	-1.0025(-0.90)	-1.0354(-0.93)	-1.0410(-0.93)
Edu	1.3614(0.91)	1.3560(0.91)	1.4187(0.94)	1.4294(0.96)
E	0.0595(1.34)	0.0616(1.39)	0.0622(1.37)	0.0628(1.39)
Dens	-0.2318(-0.76)	-0.2523(-0.82)	-0.2363(-0.76)	-0.2355(-0.76)
City-fixed effect	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
N	2493	2493	2493	2493
Adj R^2	0.4141	0.4145	0.4133	0.4132

*Notes: t statistics are in parentheses; robust standard errors are clustered at city level; * p < 0.1, ** p < 0.05, *** p < 0.01.*

4.4. Mechanism analysis

We further delved into the specific mechanism through which green trade affects the environment. Trade in

EGs is an important rule to promote the diffusion of green technologies. In contrast, green technological progress is the most effective way to realize sustainable development.

We expected increased trade in EGs to influence pollution via indigenous environmental innovation, which we primarily measured with two variables. The first one is patents on environmental technology, namely, green patents (GRT). Patents are publicly available documents with a long history in some developing countries. We linked the patent data from the State Intellectual Property Office of China (SIPO) to the IPC Green Inventory and singled out the city-level patenting relevant to environmental technology. The second is green total factor productivity (GTFP). Unlike the measures of TFP growth, the concept of GTFP incorporates emissions as undesirable output into the production function. We calculate GTFP growth via a directional distance function (DDF) by using the non-parametric Global Malmquist-Luenberger (GML) index and decompose it into green technical progress and green efficiency change (Chung et al., 1997; Oh, 2010). Green technical change (TC) captures the change in green technology, and the value of more than 1 represents an increase in green technical progress and vice versa.

Table 4. Mechanism analysis.

	(1) GRT	(2) GRT	(3) GRT	(4) TC	(5) TC	(6) TC
L3.GT	0.0066*** (3.14)					
L3.GEX		0.0040* (1.96)				
L3.GIM			0.0015 (1.46)			
L.GT				-0.0042 (-0.17)		
L.GEX					3.4447** (2.27)	
LGIM						-92.2728 (-0.83)
S	-1.5889 (-1.55)	-1.5576 (-1.51)	-1.6096 (-1.57)	-6.6889 (-0.80)	-654.2221 (-0.78)	-6.733e+04 (-0.79)
S^2	0.0645 (1.34)	0.0633 (1.31)	0.0657 (1.36)	0.4799 (1.33)	47.8023 (1.32)	4849.0505 (1.34)
Reg	-0.0006 (-0.68)	-0.0007 (-0.71)	-0.0006 (-0.62)	-0.0104 (-1.03)	-1.1096 (-1.10)	-102.6744 (-1.02)
Str	0.0163*** (2.96)	0.0161*** (2.91)	0.0160*** (2.89)	0.0947** (2.29)	9.5321** (2.31)	957.2043** (2.30)
FDI	0.0524*** (-2.73)	0.0519*** (-2.70)	0.0507*** (-2.62)	0.0846 (1.00)	8.4854 (1.01)	816.9931 (0.96)
GOV	0.0067 (1.49)	0.0067 (1.50)	0.0065 (1.45)	0.1201*** (3.73)	12.1652*** (3.81)	1211.0781*** (3.75)
K/L	-0.0994 (-0.79)	-0.1029 (-0.81)	-0.0920 (-0.73)	2.4471** (2.11)	245.9014** (2.10)	24761.4835** (2.13)
Edu	-0.0202 (-0.18)	-0.0216 (-0.20)	-0.0180 (-0.16)	0.3975 (0.69)	39.6169 (0.68)	3854.5524 (0.66)
E	0.0030 (0.60)	0.0030 (0.61)	0.0031 (0.63)	0.0306 (0.51)	3.0569 (0.51)	303.7397 (0.51)
Dens	0.0902 (1.48)	0.0916 (1.50)	0.0919 (1.50)	0.0562 (0.11)	6.0024 (0.12)	608.4425 (0.12)
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1939	1939	1939	2493	2493	2493
Adj R^2	0.9537	0.9535	0.9535	0.3657	0.3664	0.3659

*Notes: t statistics are in parentheses; robust standard errors are clustered at city level; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

In models 1–3, we performed additional tests for the number of green patent grants. Then we ran models 4–6 by replacing the dependent variable with the indicator of green technical change. Similarly, we distinguished specific flows in our specifications to identify different channels of exports and imports at work. Although green trade exerts an insignificant effect on green technical change, it appears to improve Chinese cities' green patent grants. Green exports can increase both green technical change and green patent grants, while green imports seem less effective. The authors conclude that the technology channel exists and mainly works through green exports. Though the learning process made possible by imports and exports lowers the future innovation cost, there are more reasons for exports to help boost environmental innovation. On the one hand, access to international markets will encourage firms' investments in R&D to face the uncertainty and competition from the international market. On the other hand, exposure to environmental requirements from leading importers will incentivize EG exporters to engage in upgrading their environmental technologies.

5. Conclusion

Sustainable development is the general trend of global development, and EGs undoubtedly have colossal market potential and development prospects. China is firmly integrated into global value chains and is often the focus of attention due to its rapidly increasing trade and challenging environmental problems. In this context, the authors have created a panel dataset for 277 Chinese cities from 2003 to 2014 to examine the effects of green trade on pollution levels.

The main conclusion of this study is that China could greatly benefit from increased trade in EGs, both in terms of environmental quality and green technology progress. However, accompanying measures would be necessary to ensure the potential for improving environmental quality provided by green trade, including financial and technical support that can enhance a region's capacity to position itself positively in global green chains and absorb environmental technologies. Policymakers need to consider domestic financing institutions and environmental regulations in future policymaking. For example, the government can actively promote the development of green finance by helping private market participants to identify and invest in eco-industries and eco-firms. Furthermore, nurturing a desirable environment for domestic innovation can improve the international competitiveness of environmental products. It is cautioned that green ordinary trade performs better than green processing trade concerning environmental impacts. Therefore, improving the efficiency of processing trade enterprises and the quality of trade products will guide the direction of the transformation and upgrading of trade, thus advancing the low-carbon economy.

This paper inevitably leaves some areas for further research. First, more work is needed to increase the confidence of the estimates, such as finding an exogenous shock to better identify causal correlations. Further work should also consider the role of spatial dependence among different regions. Second, a theoretical model is needed to uncover the underlying channels. For instance, green trade may increase the proportion of local green industries to benefit the environment. However, due to the imperfect definition and data of the green industry, the authors did not investigate it here. Finally, this study only focused on the environmental role of green trade while ignoring other impacts, such as its effects on the economy and society, which are worth exploring.

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Declaration of Competing Interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Appendix

A1. Composition of EGs group lists examined in this paper, by HS 6-digit code.

Class A

OECD + APEC list for 'end-of-pipe products'	142 items	230210, 252100, 252220, 281410, 281511, 281512, 281610, 281830, 282010, 282090, 282410, 283210, 283220, 283510, 283521, 283523, 283524, 283525, 283526, 283529, 283822, 380210, 392020, 392490, 392690, 560314, 580190, 591190, 681099, 690210, 690220, 690290, 690310, 690320, 690390, 690919, 701710, 701720, 701790, 730900, 731010, 731021, 731029, 732510, 780600, 840410, 840510, 840991, 841000, 841320, 841350, 841360, 841370, 841410, 841430, 841440, 841459, 841480, 841490, 841780, 841790, 841940, 841960, 841989, 842119, 842121, 842129, 842139, 842191, 842199, 842220, 842381, 842382, 842389, 842490, 842833, 846291, 847290, 847410, 847432, 847439, 847982, 847989, 847990, 848110, 848130, 848140, 848180, 850590, 851410, 851420, 851430, 851490, 851629, 870892, 890710, 890790, 901320, 901540, 901580, 901590, 902229, 902290, 902511, 902519, 902580, 902590, 902610, 902620, 902680, 902690, 902710, 902720, 902730, 902740, 902750, 902780, 902790, 902830, 902890, 903010, 903020, 903031, 903039, 903083, 903089, 903090, 903110, 903120, 903130, 903149, 903180, 903190, 903220, 903281, 903289, 903290, 903300, 960310, 960350, 980390
OECD + APEC list for 'cleaner technologies and products' (including resource management products)	32 items	220100, 220710, 280110, 284700, 285100, 290511, 320910, 320990, 381500, 391400, 460120, 700800, 701990, 840420, 840999, 841011, 841012, 841013, 841090, 841381, 841911, 841919, 841950, 841990, 843680, 850231, 853931, 854140, 854389, 902810, 902820, 903210
Other EGs	46 items	284700, 392321, 392329, 392620, 401519, 440130, 441700, 611610, 630533, 630611, 630612, 630619, 640110, 640191, 640192, 640199, 691010, 691090, 820110, 820120, 820130, 820140, 820150, 820160, 820190, 820210, 842820, 842832, 842833, 842839, 842890, 842959, 847490, 850530, 850590, 850810, 850820, 850880, 850890, 850910, 850930, 853949, 870490, 870892, 900490, 902000

Source: organized by the authors.

Class B

Clean Technologies (CT)	86 items	392510, 731010, 731100, 732211, 732219, 732290, 761100, 761300, 830249, 840211, 840212, 840219, 840220, 840290, 840310, 840390, 840410, 840420, 840490, 840681, 840682, 840690, 840890, 841011, 841012, 841013, 841090, 841181, 841182, 841199, 841350, 841360, 841370, 841381, 841391, 841620, 841630, 841869, 841911, 841919, 841950, 841990, 842129, 842139, 842199, 847960, 848110, 848130, 848140, 848180, 848190, 848310, 848360, 848410, 848490, 850131, 850132, 850133, 850134, 850161, 850162, 850163, 850164, 850211, 850212, 850213, 850220, 850231, 850239, 850240, 850300, 850421, 850422, 850423, 850431, 850432, 850433, 850434, 850440, 850490,

		851150, 851610, 851621, 854140, 900190, 900290
Environmentally Preferable Products (EPP-core)	106 items	050900, 121110, 121120, 121190, 130110, 130120, 130190, 130219, 140190, 140310, 140390, 140410, 150510, 150590, 152110, 152190, 230690, 230890, 310100, 320190, 320300, 320910, 321000, 400110, 400121, 400122, 400129, 400280, 450110, 450200, 450310, 450390, 460120, 460191, 460210, 480610, 500200, 500400, 500600, 500710, 500720, 500790, 510111, 510119, 510121, 510129, 510130, 510310, 510320, 510400, 510510, 510521, 510529, 510610, 510710, 510910, 510910, 511111, 511119, 511190, 511211, 511219, 511290, 511290, 530110, 530121, 530129, 530210, 530290, 530310, 530410, 530521, 530591, 530710, 530720, 530810, 530890, 531010, 531090, 531100, 531100, 560710, 560721, 560729, 560750, 560890, 570110, 570220, 570231, 570241, 570251, 570291, 570310, 580110, 581099, 600129, 600199, 600241, 600291, 630120, 630510, 670100, 680800, 850680, 850780, 960310

Source: organized by the authors.

Class C

Air pollution control	13 items	840420, 840490, 840510, 841410, 841430, 841440, 841459, 841480, 841490, 841960, 841989, 842139, 902610
Solid and hazardous waste management	31 items	392010, 560290, 680620, 681599, 730900, 731010, 731021, 731029, 761290, 840219, 840290, 840410, 841320, 841350, 841360, 841370, 841780, 841790, 841940, 842220, 842290, 842940, 846291, 847420, 847982, 847989, 847990, 851410, 851420, 851430, 851490
Wastewater management and water treatment	91 items	391400, 392290, 392510, 560314, 591190, 691010, 732490, 820750, 820760, 841381, 841939, 842121, 842129, 842199, 842833, 848110, 848111, 848112, 848113, 848114, 848115, 848116, 848117, 848118, 848119, 848120, 848121, 848122, 848123, 848124, 848125, 848126, 848127, 848128, 848129, 848130, 848131, 848132, 848133, 848134, 848135, 848136, 848137, 848138, 848139, 848140, 848141, 848142, 848143, 848144, 848145, 848146, 848147, 848148, 848149, 848150, 848151, 848152, 848153, 848154, 848155, 848156, 848157, 848158, 848159, 848160, 848161, 848162, 848163, 848164, 848165, 848166, 848167, 848168, 848169, 848170, 848171, 848172, 848173, 848174, 848175, 848176, 848177, 848178, 848179, 848180, 848130, 848140, 854370, 854389, 854390
Clean up or remediation of soil and water	4 items	842119, 842191, 851629, 890790
Renewable energy	38 items	730820, 840211, 840212, 840219, 840220, 840310, 840390, 840410, 840510, 840590, 840681, 840682, 840690, 841011, 841012, 841013, 841090, 841182, 841199, 841919, 841950, 841990, 848610, 850161, 850162, 850163, 850164, 850300, 850231, 850239, 850421, 850422, 850440, 854140, 854190, 900190, 900290, 901380
Environmentally preferable products (EPPs)	28 items	290511, 292218, 382490, 441872, 460129, 482361, 530310, 530110, 530121, 530129, 530390, 530500, 530610, 530620, 530710, 530720, 530911, 530919, 530921, 530929, 531010, 531090, 560710, 560721, 560729, 560900, 630510, 680800
EST-EGs with clearer environmental end-use	11 items	848230, 848240, 848250, 848280, 850300, 842139, 842121, 842129, 851410, 851420, 851430

Source: organized by the authors.

A 2. China's 277 cities examined in this paper, grouped by province.

	Province	number	City
The eastern		1	Beijing

part		1	Tianjin
	Hebei	11	Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang, Hengshui
	Liaoning	14	Shenyang, Dalian, Anshan, Fushun, Benxi, Dandong, Jinzhou, Yingkou, Fuxin, Liaoyang, Panjin, Tieling, Chaoyang, Huludao
		1	Shanghai
	Jiangsu	13	Nanjing, Wuxi, Xuzhou, Changzhou, Suzhou, Nantong, Lianyungang, Huaian, Yancheng, Yangzhou, Zhenjiang, Taizhou, Suqian
	Zhejiang	11	Hangzhou, Ningbo, Wenzhou, Jiaxing, Huzhou, Shaoxing, Jinhua, Quzhou, Zhoushan, Taizhou, Lishui
	Shandong	17	Jinan, Qingdao, Zibo, Zaozhuang, Dongying, Yantai, Weifang, Jining, Taian, Weihai, Rizhao, Laiwu, Linyi, Dezhou, Liaocheng, Binzhou, Heze
	Guangdong	20	Guangzhou, Shaoguan, Shenzhen, Zhuhai, Shantou, Foshan, Jiangmen, Zhanjiang, Maoming, Zhaoqing, Huizhou, Meizhou, Shanwei, Heyuan, Yangjiang, Qingyuan, Dongguan, Zhongshan, Chaozhou, Jieyang
	Fujian	9	Fuzhou, Xiamen, Putian, Sanming, Quanzhou, Zhangzhou, Nanping, Longyan, Ningde
	Hainan	2	Haikou, Sanya
The central part	Shanxi	11	Taiyuan, Datong, Yangquan, Changzhi, Jincheng, Shuozhou, Jinzhong, Yuncheng, Xinzhou, Linfen, Lvliang
	Jilin	8	Changchun, Jilin, Siping, Liaoyuan, Tonghua, Baishan, Songyuan, Baicheng
	Heilongjiang	12	Harbin, Qiqihar, Jixi, Hegang, Shuangyashan, Daqing, Yichun, Jiamusi, Qitaihe, Mudanjiang, Heihe, Suihua
	Anhui	16	Hefei, Wuhu, Bengbu, Huainan, Maanshan, Huaibei, Tongling, Anqing, Huangshan, Chuzhou, Fuyang, Suzhou, Lu’an, Bozhou, Chizhou, Xuancheng
	Jiangxi	11	Nanchang, Jingdezhen, Pingxiang, Jiujiang, Xinyu, Yingtan, Ganzhou, Jian, Yichun, Fuzhou, Shangrao
	Henan	17	Zhengzhou, Kaifeng, Luoyang, Pingdingshan, Anyang, Hebi, Xinxiang, Jiaozuo, Puyang, Xuchang, Luohe, Sanmenxia, Nanyang, Shangqiu, Xinyang, Zhoukou, Zhumadian
	Hubei	12	Wuhan, Huangshi, Shiyan, Yichang, Xiangyang, Ezhou, Jingmen, Xiaogan, Jingzhou, Huanggang, Xianning, Suizhou
	Hunan	13	Changsha, Zhuzhou, Xiangtan, Hengyang, Shaoyang, Yueyang, Changde, Zhangjiajie, Yiyang, Chenzhou, Yongzhou, Huaihua, Loudi
The western part	Neimenggu	7	Hohhot, Baotou, Wuhai, Chifeng, Hulunbeier, Bayannaoer, Wulanchabu
	Guangxi	14	Nanning, Liuzhou, Guilin, Wuzhou, Beihai, Fangchenggang, Qinzhou, Guigang, Yulin, Baise, Hezhou, Hechi, Chongzuo
		1	Chongqing
	Sichuan	18	Chengdu, Zigong, Panzhihua, Luzhou, Deyang, Mianyang, Guangyuan, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Guangan, Dazhou, Yaan, Bazhong, Ziyang
	Guizhou	3	Guiyang, Zunyi, Anshun
	Yunnan	4	Kunming, Qujing, Yuxi, Baoshan, Zhaotong, Lijiang, Puer, Lincang
	Shannxi	10	Xian, Tongchuan, Baoji, Xianyang, Weinan, Yanan, Hanzhong, Yulin, Ankang, Shangluo
	Gansu	12	Lanzhou, Jiayuguan, Jinchang, Baiyin, Tianshui, Wuwei, Zhangye, Pingliang, Jiuquan, Qingyang, Dingxi, Longnan
	Qinghai	1	Xining
	Ningxia	2	Yinchuan, Shizuishan
	Xingjiang	2	Urumqi, Karamay

Source: organized by the authors.

A 3. Definition of Variables.

Variable	Name	Definition
P	Environmental pollution	Constructed by entropy method using data on industrial three wastes (wastewater, waste gas, solid waste) and $PM_{2.5}$
GT	Green trade	Trade in EGs/total trade
TT	Total trade	Total trade/GDP
GIM	Green imports	Imports of EGs/total imports
GEX	Green exports	Exports of EGs/total exports
GOT	Green ordinary trade	Ordinary trade in EGs/total ordinary trade
GPT	Green processing trade	Processing trade in EGs/total processing trade
S	GDP per capita	GDP/population
Reg	Environmental regulation	Utilization rate of solid waste
Str	Industrial structure	Output of the second industry/GDP
FDI	FDI	FDI/GDP
Gov	The degree of government intervention	Government expenditure/GDP
K/L	Capital-labor ratio	Capital/labor
Edu	Human capital	Net fixed assets / total assets
E	Energy consumption	Each city's annual electricity consumption
Dens	Density	Population/land area
FMA	Foreign Market Access	Closest distance from cities to three ports (Hong Kong, Shanghai and Tianjin)
GGT	Global green trade	Proportion of global green trade
Fin	Purchasing power	Total deposits and loans of urban financial units/GDP
Abs	Absorptive capacity	One year lag of the total granted patent data
GRT	Green patent grants	Ln (the number of green patent grants+1)
TC	Technical change	Green technical change

Source: organized by the authors.

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