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TRADE OPENNESS AND THE ENVIRONMENTAL KUZNETS CURVE: EVIDENCE FROM CITIES IN THE PEOPLE'S REPUBLIC OF CHINA

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Abstract

This paper examines the impact on the environment of economic growth and trade openness in 261 cities in the People's Republic of China (PRC) over the period 2004–2013, using a recently developed, continuously updated, fully modified method that allows for cross-sectional dependence and endogeneity. The study investigates two types of pollutant, industrial wastewater and sulfur dioxide, and employs three measures of openness in the regression. The results show that the environmental Kuznets curve hypothesis holds not only for the whole of the PRC but also for different regions. The paper estimates that wastewater pollution increases with economic development until the per capita gross domestic product (GDP) reaches the turning point of CNY31,849–CNY49,446 (in constant 2002 prices), which varies depending on the specific measure of trade openness. It finds that the turning point for sulfur dioxide occurs at a much lower income level, around CNY9,274–CNY10,103 per capita GDP. Furthermore, the results indicate that cities featuring greater openness tend to have lower industrial wastewater emissions but higher sulfur dioxide emissions.

Keywords: environmental Kuznets curve, trade openness, People's Republic of China

JEL Classification: C33, F18, Q42, Q43

Contents

1. INTRODUCTION

With an increase in the intensity of environmental degradation, the relationship between economic growth and the environment has attracted growing attention in the People's Republic of China (PRC). Grossman and Krueger (1995) put forward the environmental Kuznets curve (EKC) hypothesis, which refers to an inverted U-shaped relationship between environmental degradation and per capita income; that is, the environmental quality initially deteriorates but then improves as per capita income rises. This hypothesis has since become one of the most hotly debated issues in environmental economics. Empirical studies on the EKC hypothesis have presented mixed results (Shafik and Bandyopadhyay 1992; Antweiler, Copeland, and Taylor 2001; Cole 2004; Stern 2004; Jalil and Feridun 2011) and have focused on developed countries. Other studies have tried to incorporate openness into the EKC analysis. Although much theory and evidence indicate that trade is closely related to income and economic growth, the environmental effect of trade differs systematically from that of economic growth (Copeland and Taylor 1994). Growth inevitably increases pressure on pollution if there is no environmental policy. However, demand for environmental quality also increases with income. The net effect reflected by the EKC depends on the income elasticity of the demand for environmental quality. If the income elasticity of the demand for environmental quality is 1, governments will respond to deteriorating pollution by tightening up the environmental policy. As a result, the scale and technique effects exactly offset each other, resulting in neutral economic growth without changes in environmental quality.[1]However, trade driven by comparative advantage yields very different environmental outcomes. According to the pollution haven hypothesis (PHH), countries or regions with comparative advantage in polluting industries will observe the concentration of industries with high emission intensity and experience environmental degradation. In contrast, countries or regions with comparative advantage in clean industries will observe the concentration of industries with low emission intensity and experience environmental improvement. Consequently, the growth path for an open economy could be more polluting than the growth path for a closed economy. However, trade openness may improve the environment in cities if openness helps to modernize the capital stock, enabling the technology effect to outweigh the scale effect. Hence, the impact of trade on pollution is uncertain and needs scrutiny.

This paper investigates the EKC and its turning point using different measures of trade openness in the Chinese context. Most empirical studies on the EKC hypothesis have used panels of country-level data over time, despite the fact that the EKC theory essentially depicts the dynamic path of the relationship between environmental quality and economic growth within a single country (Shafik and Bandyopadhyay 1992; Antweiler, Copeland, and Taylor 2001; Cole 2004; Stern 2004; Jalil and Feridun 2011). Hence, this paper assesses how trade affects the relationship between economic growth and pollution in a single country, the PRC, using city-level data. Cities play an important role in shaping the PRC's trade, production, and emissions. Liu (2015) shows that 85% of carbon emissions in the country are attributed to urban economic activities. Although the concentrations of production and emissions are expected to increase due

[1] The impact of trade openness on the environment can be decomposed into scale, technology and composition effects (Grossman and Krueger 1991; Copeland and Taylor 1994; Cole and Elliott 2003). The scale effect refers to the likely increase in emissions resulting from the overall economic growth generated by trade openness. The technology effect accompanying trade liberalization is expected to decrease the emission intensity through the usage of clean production technology. The composition effect refers to the change of economic structure that may occur when countries specialize in the production in which they have a comparative advantage.

to the rapid and large-scale urbanization process, the patterns and dynamics of the city-level growth, trade, and environment nexus remains largely unexplored.

Furthermore, Chinese cities provide a unique setting to study this issue, because both the trade sector and pollution have grown rapidly over the past three decades. In 1980, the PRC accounted for only 0.92% of world trade. However, 32 years later, this ratio had risen steeply to 10.48% (Wang 2014). In 2016, the PRC exported 13.2% and imported 9.8% of the world merchandise trade (WTO 2017a). In 2014–2016, trade amounted to $1,601 trillion and accounted for 20% of its GDP (WTO 2017b). However, accompanied by the fast-growing trade sector, environmental degradation—such as deteriorating water quality, land deforestation, pollution, and frequent haze plagues—has attracted a great deal of attention. The World Bank (2007) estimated the economic burden of premature mortality and morbidity associated with air pollution to be over $19 billion in 2003, or 1.16% of the GDP.

In this paper, we attempt to answer the following question: What does trade liberalization/openness bring to Chinese cities and how does it facilitate the movement of cities on the EKC curve? Specifically, we analyze the impact of trade openness on the EKC using emissions of industrial pollutants, industrial wastewater, and sulfur dioxide (SO_2) in cities. The empirical evidence supports the EKC relationship. We find that the turning points of the inverted U-shaped curve for wastewater are around CNY31,849–CNY49,446 per capita GDP and CNY9,274–CNY10,103 for SO_2. Besides, we show that trade openness has a negative impact on wastewater emissions but a positive effect on SO_2. Furthermore, the results from the regional analysis indicate that the EKC relationship holds in different regions. However, if we group the cities by their level of openness, we find that the EKC hypothesis is only true in cities with a high level of trade openness, suggesting that trade openness is a key determinant of the relationship between environment and income.

We contribute to the ongoing debate in several respects. First, we infer the effect of income on pollutant emissions with a state-of-the-art empirical method. The reduced-form models that we apply to the empirical study of the EKC reflect correlation rather than a causal mechanism (Cole 2004; Kijima, Nishide, and Ohyama 2010) due to the potential feedback effect from environmental quality to income growth. The recent EKC literature has adopted different econometric methods to solve this concern of reverse causality, including system generalized method of moments (GMM) (Li, Wang, and Zhao 2016), the spatial panel model (Kang, Zhao, and Yang 2016), and fully modified ordinary least squares (OLS) (Kasman and Duman 2015), among others. In this paper, we employ the recently developed continuously updated fully modified (Cup-FM) estimates (Bai, Kao, and Ng 2009) to address the endogeneity concern and cross-sectional dependence. To implement this estimator, we first test for the cross-sectional dependence of the panel and employ the cross-sectionally augmented Im, Pesaran, and Shin (CIPS) test (Pesaran 2007) to examine the presence of unit roots in the panel. For the purpose of comparison, we also conduct fixed-effect regressions and difference and system GMM estimations. The empirical results indicate that Cup-FM estimates generate more robust results than other estimations.

Secondly, our empirical analysis of the growth-trade-environment nexus in the PRC is performed on the most recent prefectural level data covering 261 cities for the period of 2004–2013. Given the differentiated impacts of economic growth and trade on the environment, as well as the variation of comparative advantage and stringency of environmental regulation across Chinese cities, the aggregate measures mask regional and sectoral variation. The income gap between coastal and inland Chinese cities is remarkable. For instance, GDP per capita in Shenzhen amounted to $25,135 in 2015, while Dingxi in Gansu Province has a per capita GDP of only $1,748 in the same year.[2] In 2004, the trade openness measured by the ratio of export and import to GDP was as high as 4.62 in Dongguan of Guangdong Province, but only 0.00094 in Shangluo of Shaanxi Province. The huge regional gap implies that the shape of the EKC varies dramatically across different cities. Surprisingly, few researchers have investigated the EKC at the city level in the PRC. Most studies on EKC or the pollution haven hypothesis in the PRC focus on the provincial level (Auffhammer 2002; de Groot, Withagen, and Zhou 2004; He 2009; Kang, Zhao, and Yang 2016; Li, Wang, and Zhao 2016). However, income, emissions, and trade data for the PRC display considerably variations across cities even within the same province. Moreover, over the past two decades, the PRC’s environmental policy has become increasingly decentralized (Auffhammer and Carson 2008; Zheng and Kahn 2017). Local governments in rich areas are starting to enforce stricter environmental regulations (Zheng and Kahn 2013). A couple of researches have been implemented at the city-level but with relatively old data (Cole, Elliott, and Zhang 2011; Zheng and Kahn 2013). All these motivate us to implement a city-level research on the growth-trade-pollution nexus.

Thirdly, we divide the city sample into three regions, East, Middle, and West, to examine the robustness of the EKC hypothesis across regions. These three regions were officially classified by the PRC’s seventh Five-Year Plan (1986–1990). Although they are named geographically, the division reflects the differences in regional priorities in economic development and, more importantly, the setting up of a pecking order in resource allocation. The eastern PRC was first open to foreign investment in the 1980s and enjoyed preferential policies that significantly enhanced local economic growth. Although all the capital cities of inland provinces were gradually opened to foreign capital after 1992, the gap between coastal and inland cities is still remarkable. The coastal cities are well recognized for being densely populated, as well as culturally and economically influential, while the inland cities usually have lower income per capita. Limited access to capital and advanced technology, coupled with skilled labor migrating into more developed coastal regions, may have prevented the inland areas from catching up (Huang et al. 2016). This exercise helps us better understand how the environmental quality varies across regions due to the dynamics of openness and economic growth. In addition, we consider two subsamples with regard to trade openness, through which we try to determine whether trade openness has an impact on the relationship between pollution emissions and cities’ economic development. The in-depth analysis of the EKC relationship in various dimensions constitutes our understanding of the potential drivers of the curve.

We organize the remainder of this paper as follows. Section 2 connects the study with the previous literature. Section 3 discusses the data and econometric methodology. Section 4 presents the empirical results. Section 5 concludes the paper and discusses the policy implications.

2. LITERATURE REVIEW

This paper is closely related to two strands of literature. The first strand discusses the link between economic growth and environment; the second strand of literature analyzes the impact of openness on the environment. Dasgupta et al. (2002) and Copeland (2018) have completely reviewed these two strands from an international perspective. Our focus is mainly on research related to the PRC.

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2 GDP data are taken from the CEIC China Premium Database. Exchange rate is obtained from the Bank for International Settlements (BIS).

2.1 Economic Growth and Environment

The existing literature has extensively studied the link between growth, trade, and the environment, and has indicated that the EKC hypothesis is more likely to hold for pollutants like sulfur dioxide. A change in production, energy consumption, and hence emissions can be decomposed into scale, technology, and composition effects (Copeland and Taylor 1994; Grossman and Krueger 1995; Suri and Chapman 1998; Cole 2004; Jalil and Mahmud 2009). The scale effect refers to the likely increase in emissions resulting from the overall economic growth that trade openness generates. The technology effect accompanying trade liberalization is expected to decrease the emission intensity through the usage of clean production technology. The composition effect refers to the change in the economic structure that may occur when countries specialize in the production in which they have a comparative advantage. Numerous theoretical and empirical papers have investigated the EKC hypothesis. However, due to the adoption of different samples, pollutants, and methodologies, the conclusions vary and the causal linkage remains unclear.

The debate about the existence of the EKC in the PRC has been intense in the last two decades (Yang, He, and Chen 2015). Most of existing researches are based on provincial-level panel data. Auffhammer and Carson (2008) suggest that the anticipated path of the PRC's carbon dioxide emissions has dramatically increased since the beginning of the twenty-first century. Kang, Zhao, and Yang (2016) adopt a spatial panel model to examine the EKC hypothesis on carbon dioxide (CO_2) in 30 PRC provinces, and find an inverted-N shape between economic growth and CO_2 emissions. Li, Wang, and Zhao (2016) use the system GMM in a dynamic panel model and an autoregressive distributed lag (ARDL) model to investigate the EKC hypothesis in 28 PRC provinces, and find that the EKC hypothesis is well supported for CO_2, wastewater, and waste solid emissions.

Several new researches have started to examine the validity of the EKC using city-level data. Cole, Elliott, and Zhang (2011) investigate the impact of economic growth and foreign direct investment (FDI) on industrial pollution emissions in 112 major PRC cities over four years from 2001 to 2004. They discover an inverted-U EKC-type curve with a turning point between RMB32,4557 and RMB35,098 for wastewater and a turning point between RMB17,233 and RMB23,866 for petroleum-like matter. At that time, very few PRC cities passed the turning point, indicating that most are on the upward sloping side of the EKC. "Turning points, where estimated, are at income levels that are often beyond the sample income range, sometimes considerably so" (Cole, Elliott, and Zhang 2011: 123). Using a panel database of 74 PRC cities for the period 1990–2001, He and Wang (2012) show that economic structure, development strategy, and environmental regulation can have important implications for the relationship between environmental quality and economic development, but the impact can vary at different development stages. Zheng et al. (2014) are the first to assess how public concern and the local leadership's characteristics influence the EKC across PRC cities.

There is some criticism of the EKC. For example, Harbaugh, Levinson, and Wilson (2002) reexamined the EKC hypothesis using a panel of worldwide cities and found that the results are sensitive to changes in model specifications. Stern (2004) summarized four main econometric criticisms of the EKC hypothesis: heteroskedasticity, simultaneity, omitted variable bias, and cointegration issues. Perman and Stern (2003) argued that cointegration analysis is imperative to test the validity of the EKC, given that the data usually contain stochastic trends. Wagner (2008; 2015) also pointed out the inadequate application of unit root and cointegration techniques in a number of empirical studies. He noted that standard panel cointegration tests are not appropriate when there are short time dimensions, nonlinear transformations of integrated variables, or cross-sectional dependence in the data. In this paper, we employ the continuously updated fully modified method that Bai, Kao, and Ng (2009) developed to deal with endogeneity and cross-sectional dependence issues.

With regard to the turning point, the results in a number of studies have shown a wide range. For instance, Grossman and Krueger (1995) indicated that the turning point of the EKC curve was around $8,000 per capita for most pollutants. The turning point for SO_2 emissions that Stern and Common (2001) estimated was over $100,000. This may arise from the difference in samples, pollutants, models, and econometric methods.

The earliest models were simple quadratic functions of per capita income. Then some researchers included the GDP-cubed term and found that the relationship is of an N (or S) shape, implying that environmental degradation accelerates again after decreasing to a certain level (Kijima, Nishide, and Ohyama 2010). Zheng and Kahn (2013) identified an S-shape of the PM10-GDP linkage using PRC city-level data and obtained a peak point at around $4,900 per capita. In this paper, we adopt the quadratic function of per capita income due to the relatively short time span.

2.2 Openness and Environment

Being closely related with income and economic growth, trade openness impacts the environment through scale effects, composition effects, and technology effects. Shafik and Bandyopadhyay (1992) found all indicators of trade policy to have insignificant impacts on water shortage and sanitation and municipal waste, but more open countries put less pressure on forest resources and tend to have lower levels of sulfur dioxide and carbon emissions. Using pooled cross-country and time-series data, Suri and Chapman (1998) show that export of manufactured goods by industrialized countries is an important factor in generating the upward sloping portion of the EKC, while import by industrialized countries contributed to the downward slope. Antweiler, Copeland, and Taylor (2001) investigated the effects of openness to trade on SO_2 concentrations and estimated three trade-induced effects. They found that freer trade appears to be good for the environment. Managi, Hibiki, and Tsurumi (2009) discovered a positive effect of trade openness on CO_2 emissions for non-OECD countries, indicating the scale effect from trade-driven increases in industrial production. Zhang (2012) found that the changes in input mix, sector energy intensity, fuel mix, and carbon intensity of fuels can offset the increasing trade-induced carbon emissions in twenty-six sectors, including agriculture, mining, manufacturing, and service industries. Using the autoregressive distributed lag (ARDL) methodology, Jalil and Mahmud (2009) and Jalil and Feridun (2011) concluded that there is a quadratic relationship between income and CO_2 emissions, and that trade openness has a positive significant impact on carbon emissions in the PRC Li, Wang, and Zhao (2016) find some evidence that trade and urbanization may deteriorate environmental quality in the long run, not in the short run. A more complete and timely review on this strand of literature can be found in Copeland (2018).

In addition to these three channels, trade affects the environment through comparative advantage across countries. A popular theory, the pollution haven hypothesis (PHH), was first developed by Pethig (1976) and McGuire (1982), and later improved by Copeland and Taylor (1994), Levinson and Taylor (2008), Zeng and Zhao (2009), Dijkstra, Mathew, and Mukherjee (2011), and Tang (2015), among others. It claims that developing countries with inefficiently low environmental standards or weak enforcement may attract foreign investment that seeks to reduce the pollution abatement costs and maximize economic gains, and as a result, FDI would aggravate pollution in the host countries. Other studies have investigated the environmental impact of FDI by suggesting that a 'pollution halo' may exist around multinational firms if those firms are less pollution-intensive than domestic firms. Dasgupta et al. (2002) cast doubt on the 'race to the bottom' scenario, which indicates that outsourcing dirty production to developing countries where the environmental regulations are less strict lowers the pollutant emissions in developed countries. They argued that liberalization is good for the environment. Studies such as those by Eskeland and Harrison (2003) and Cole, Elliott, and Strobl (2008) do indeed find evidence to suggest that multinational firms in developing economies are less pollution-intensive than their domestic counterparts. Zeng and Eastin (2007) examine the effects of trade openness and FDI on industrial pollution levels across the PRC's provinces over the period 1996–2004. They find that increased trade openness and FDI are positively correlated with environmental protection in the PRC. Zhang (2012) finds that the changes in input mix, sector energy intensity, fuel mix, and carbon intensity of fuels can offset the increasing trade-induced carbon emissions in 26 sectors, including agriculture, mining, manufacturing, and service industries. His analysis provides some evidence that the technique effect contributes to mitigating pollution emissions arising from the energy consumption by trade-oriented sectors. Bombardini and Li (2016) create a set of measures of export shocks for Chinese cities and find that increasing exposure to trade leads to a large decline in air quality and increased health problems in regions with a comparative advantage in a pollution-intensive manufacturing industry, reflecting the important regional variations in the effects of trade on pollution. Huang et al. (2016) study the economic and environmental impacts of FDI by addressing the regional spillovers of FDI and pollution across Chinese provinces. He (2006; 2009) shows that pollution and FDI are positively correlated in the PRC, as FDI increases industrial output and pushes up carbon emissions. However, Auffhammer et al. (2016) identify the separate channels through which the inflow of FDI and environmental regulations affect city-level CO_2 emissions in the PRC and conclude that the inflow of FDI pulls down energy intensity and CO_2 emissions by generating significant technique effects.

Most of these studies measure the openness by FDI rather than trade. Although FDI is closely related to trade, their impact on the environment may differ. For example, domestic firms and multinational firms may differ in their production technology and abatement efforts. Huang et al. (2016) find that while FDI is beneficial to the environment, production by private firms is detrimental. Moreover, increased access to imported intermediate goods can lower pollution emissions if the intermediates are relatively clean. In this paper, we measure openness using different indicators so as to examine the differentiated environmental impact of exports and imports.

The previous literature therefore provides little guidance on the impact of the PRC's significant trade on the environment. This lack of guidance is compounded by the absence of examination of the city-level characteristics that influence a city's pollution emissions. This paper therefore aims to fill this gap at least partially by examining the extent to which trade and economic growth influence industrial pollution emissions in the PRC using an updated dataset for 261 cities between 2004 and 2013.

3. DATA AND METHODOLOGY

3.1 Data and Spatial Patterns

We obtain data from the China City Statistical Yearbook and CEIC China Premium Database. The definitions of the variables and the summary statistics are provided in Table 1.

Table 1: List of Variables and Summary Statistics

Variables	Definitions	Mean	Std Dev.	Min.	Max.	Obs.
lnWater	Logarithm of per capita industrial wastewater (kg)	4.940	0.908	1.136	8.581	2,610
lnGas	Logarithm of per capita industrial SO_2 (kg)	2.490	1.084	–7.097	5.553	2,610
lnGDP	Logarithm of per capita real GDP (yuan in constant 2002 prices)	9.837	0.681	7.727	11.855	2,610
lnGDP squared	Square of the logarithm of per capita real GDP	97.223	13.465	59.703	140.551	2,610
lnTrade	Logarithm of per capita real total trade (used in constant 2002 prices)	5.462	1.953	–0.751	11.783	2,610
Trade share	Ratio of total trade and GDP	0.231	0.413	0.001	4.622	2,610
lnExport	Logarithm of per capita real exports (used in constant 2002 prices)	4.924	1.970	–4.785	11.219	2,610
lnImport	Logarithm of per capita real imports (used in constant 2002 prices)	4.168	2.387	–5.296	10.942	2,610
lnElectricity	Logarithm of per capita industrial electricity use (million kWh)	0.837	1.231	–3.868	4.267	2,610
lnDensity	Logarithm of population per square kilometer (people/km^2)	5.782	0.901	1.562	7.840	2,610
Manufacturing	Share of the output from the secondary industry in the total output (percentage)	49.798	10.721	15.7	90.97	2,610
Service	Share of the output from the tertiary industry in the total output (percentage)	35.740	8.550	0	76.85	2,610

GDP per capita, pollutant emissions per capita, and trade openness all exhibit a strong agglomeration pattern in the PRC. Figures A1(a) and A1(b) in the appendix illustrate the spatial distributions of GDP per capita and two types of pollutant at city level based on their average values from 2004 to 2013. The pollutants of 261 cities are shown as a circle, where the size of the circle is proportional to the pollutant per capita of the city—i.e., the bigger the circle, the higher the level of pollution in that city. We can see that industrial wastewater per capita shares a similar pattern to GDP per capita, and most clusters remain in coastal regions, while the agglomeration of industrial SO_2 per capita mainly appears in northern provinces. Figure A1(c) presents the spatial distribution of average GDP per capita and trade openness over the same period of time. A proportional circle graph plots the openness of trade in each city. The geographic concentration of GDP per capita and trade openness is determined by government policy, agglomeration effect, and historical factors. Compared with GDP per capita, trade openness is even more concentrated in coastal PRC. The disparities between distribution of GDP per capita and trade openness indicate the necessity to incorporate the effect of trade openness into the EKC analysis. Figures A1(d) and A1(e) demonstrate the spatial density distributions of trade openness and two types of pollutant at city level, based on average data from 2004 to 2013. Unlike trade openness, high pollution cities in terms of industrial SO_2 per capita are more likely to be located in the northern PRC. Our results are broadly consistent with previous studies (Kanbur and Zhang 2005).

3.2 The Empirical Model

We consider the following EKC model:

$$lnPollution_{it} = \alpha + \beta_1 lnGDP_{it} + \beta_2 (lnGDP_{it})^2 + \beta_3 lnTrade_{it} + \beta_4 lnElectricity_{it}$$

$$+\beta_5 lnDensity_{it} + \beta_6 Manufacturing_{it} + \beta_7 Service_{it} + \varepsilon_{it} \quad (1)$$

where $lnPollution$, $lnGDP$, $lnTrade$, and $lnElectricity$ are logarithms of pollution, real GDP, total trade, and industrial electricity consumption, all expressed in per capita terms. The variable $lnDensity$ is the logarithm of population density. The variables $Manufacturing$ and $Service$ are the ratio of the output in the secondary and tertiary industries to the gross output, measuring the composition effect. The superscripts i and t denote the prefecture city and year, respectively.

In this paper, we examine two types of pollutant, industrial wastewater and industrial SO_2 emissions, because they are among the most commonly used indicators of pollution in cities and researchers have recognized their severe effects on the environment and human health for a long time (Grossman and Krueger 1995). In particular, due to the heavy reliance on coal for electricity generation, SO_2 emissions are the source of many serious environmental problems in the PRC. According to the EKC theory, there is an inverted U-shaped relationship between income and pollution; thus, we expect β_1 to be positive and β_2 to be negative. Electricity consumption tends to cause more pollution; therefore, β_4 is likely to be positive. Since the population density and the structure of the economy are also likely to affect the level of pollution through the scale and composition effect (Grossman and Krueger 1995; Cole 2004), we also include them in the regression specification. The relationship between trade and the environment is the focus of this paper. Besides using the measure of $lnTrade$, we also use alternative proxies as a robustness check, such as the ratio of total trade to GDP ($Trade\ share$) and the pair of $lnExport$ and $lnImport$, to explore further how the openness of the economy is related to the environment in a city. While no existing studies have considered the impact of exports and imports separately, these two factors may affect the pollution in local cities quite differently. Cities with huge exports of manufacturing goods tend to be more polluted than cities with huge imports of manufacturing goods, even if we can assume that the total trade is the same. We therefore conduct another regression including exports and imports simultaneously. The analysis for the whole of the PRC is repeated for three geographic regions, East, Middle, and West PRC. East PRC accounts for most of the trade and includes cities in the provinces of Hebei, Liaoning, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, and Henan and the municipalities of Tianjin, Beijing, and Shanghai. Middle PRC includes cities in Shanxi, Jilin, Anhui, Jiangxi, Henan, and Hubei provinces. The rest belong to West PRC.

3.3 Econometric Methods

The EKC literature has used different econometric methods to estimate the coefficients in the equations. Li, Wang, and Zhao (2016) used the system GMM in a dynamic panel model and an ARDL model to investigate the EKC hypothesis in 28 Chinese provinces. Kang, Zhao, and Yang (2016) adopted a spatial panel model to examine the CO_2 EKC hypothesis in 30 Chinese provinces. Kasman and Duman (2015) employed the fully modified OLS (FMOLS) method to study the dynamic causal relationship between CO_2, GDP, energy use, trade openness, and urbanization in 15 European countries for the period 1992–2010. In this paper, we use an innovative estimation, namely the Cup-FM method that Bai, Kao, and Ng (2009) proposed. The energy-growth nexus literature has recently used the Cup-FM estimator (Fang and Chang 2016; Fang and Chen 2017; Chen and Fang 2018). Unlike other estimation methods, the Cup-FM estimator allows for cross-sectional dependence and endogeneity. Furthermore, studies have shown that the Cup-FM estimator has good finite sample properties, so it fits the city panel in this paper well.

To use the Cup-FM estimator, we conduct a few pre-tests, including the panel unit root test and panel cointegration test. First, we employ the cross-sectional dependence tests that Frees (1995) and Pesaran (2004) proposed to determine the appropriate panel unit root tests. We selected Frees' (1995) test and Pesaran's (2004) cross-sectional dependence test because they are valid for samples with a large N and small T. Both tests have the null hypothesis of independence across units, and the test statistics follow the standard normal distribution asymptotically.

If the data are cross-sectionally dependent, it is necessary to employ the second-generation panel unit root tests that allow for interdependence across units (Phillips and Sul 2003; Bai and Ng 2004; Pesaran 2007). This paper uses the popular cross-sectionally dependent IPS test (CIPS) that Pesaran (2007) proposed to test for the presence of unit roots. The CIPS test considers the following specification:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \beta_0 \bar{y}_{t-1} + \sum_{j=0}^{p} d_{j+1} \Delta \bar{y}_{t-j} + \sum_{j=1}^{p} c_j \Delta y_{i,t-j} + \varepsilon_{it} \quad (2)$$

where α_i is the deterministic term, $\bar{y}_t$ is the mean of the dependent variable y_{it} for all N observations at time t, and p is the lag order selected according to an information criterion. Let t_i be the t-statistics of the coefficient estimates of ρ_i for unit i. We then define the CIPS test statistic as $CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i$. For data with a T less than 20, we propose a truncated CIPS test to avoid the problem of over-size; the truncated values of the t-statistics vary for different deterministic terms (Pesaran 2007). Since we consider annual data from 2004 to 2013, we use a truncated CIPS test statistic in this paper to examine whether the series are stationary.

If the series are not stationary, we proceed to test for a cointegrating relationship. To account for cross-sectional dependence in the data, panel cointegration tests, such as that of Westerlund (2007), are preferred. However, this is not applicable due to the short time span considered in this paper. Following Chen and Fang (2018), we consider the traditional Pedroni (1999; 2004) seven statistics instead to obtain a clue to the cointegrating relationship among the variables. The first step is to estimate the residuals based on the model

$$y_{it} = \alpha_i + \sum_{j=1}^{k} \beta_{ji} X_{jit} + \varepsilon_{it} \quad (3)$$

where we assume that y and X are integrated of order one, the superscripts i and t are the cross-sectional unit and time period, respectively, and k denotes the number of regressors. The second step is to test for the presence of unit roots in the residuals $r_{it} = \rho_i r_{it-1} + u_{it}$. Under the null hypothesis of no cointegration, $\rho_i = 1$. For the four panel statistics, the alternative hypothesis is $\rho_i = \rho < 1$ for all units; for the other three group statistics, the alternative hypothesis is $\rho_i < 1$ for all i, where ρ_i can be heterogeneous across units. Among the seven statistics, we rely more on the two Augmented Dickey-Fuller Test (ADF) statistics that perform well in the small T panel (Wagner and Hlouskova 2009).

After confirming the existence of a cointegrating relationship between the set of variables, we estimate the coefficients using the Cup-FM method. Following Bai, Kao, and Ng (2009), we consider the model $y_{it} = \alpha_i + \sum_{j=1}^{k} \beta_j X_{jit} + \varepsilon_{it}$, where the error term ε_{it} follows a factor model $\varepsilon_{it} = \lambda_i F_t + u_{it}$. The common factor F is to model the cross-sectional dependence. We can then give the Cup-FM estimator as

$$\left(\hat{\beta}_{Cup}, \hat{F}_{Cup}\right) = argmin \frac{1}{nT^2} \sum_{i=1}^{n} (y_i - x_i\beta)' M_F (y_i - x_i\beta) \quad (4)$$

where $M_F = I_T - T^{-2}FF'$ and I_T is the identity matrix of dimension T. To find the estimator, we assign an initial value to F and repeat our estimations until convergence. We prove that the Cup-FM estimator that we obtain from the iterated procedure is $\sqrt{n}T$ consistent. Moreover, it allows for cross-sectional dependence and endogeneity and has good small-sample properties.

For the purpose of comparison, we also conduct fixed-effect regressions and difference and system GMM estimation. The GMM method is appropriate for a dynamic panel with a small T and large N (Arellano and Bond 1991; Arellano and Bover 1995; Blundell and Bond 1998). Consider the following reduced-formed dynamic panel model:

$$lny_{it} = \alpha lny_{it-1} + \beta X_{it} + v_i + \varphi_t + \varepsilon_{it} \quad (5)$$

where *lny* is the logarithm of the pollutant; X is the vector of explanatory variables, including $lnGDP$, $lnGDP\ squared$, $openness$, $lnElectricity$, and the share of output from the manufacturing and service sector in the gross output; and v_i and φ_t represent the individual fixed city effect and time effect. Therefore, α captures the dynamic effect and β is a vector of coefficients associated with the explanatory variables. The difference GMM eliminates the endogeneity in the dynamic model by employing the lagged variables as the instruments (Arellano and Bond 1991). The system GMM augments the difference GMM by adding the level equation and additional instruments to solve the issue that lagged variables perform poorly for first-differenced variables (Blundell and Bond 1998).

Besides estimating the coefficients, we perform the panel Granger non-causality test that Dumitrescu and Hurlin (2012) proposed. We select it because of its good properties in a small sample and because it allows for heterogeneity and cross-sectional dependence following a block bootstrap procedure. Consider the panel model:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \rho_{i,k} y_{i,t-k} + \sum_{k=1}^{K} \beta_{i,k} x_{i,t-k} + \varepsilon_{i,t} \quad (6)$$

To test whether the series $\{x_{i,t}\}$ Granger cause $\{y_{i,t}\}$, Dumitrescu and Hurlin (2012) proposed following these steps: (1) obtain the standardized test statistics $Z_{N,T} = \sqrt{\frac{N}{2K}}(W_{N,T} - K)$ and $\tilde{Z}_N = \frac{\sqrt{N}[W_{N,T} - E(\tilde{W}_{i,T})]}{\sqrt{Var(\tilde{W}_{i,T})}}$, where $W_{N,T}$ is the average of N Wald statistics $\tilde{W}_{i,T}$ obtained from the estimation for each cross-section unit; (2) obtain the empirical critical values. To do this, assume that $\beta_{i,k} = 0$ and calculate the estimates $\hat{\alpha}_i$ and $\hat{\rho}_{i,k}$ and residuals $\hat{\varepsilon}_{i,t}$. Next, construct a new series $\{\tilde{y}_{i,t}\}$ where $\tilde{y}_{i,t} = \hat{\alpha}_i + \sum_{k=1}^{K} \hat{\rho}_{i,k} y_{i,t-k} + \hat{\varepsilon}_{i,t}$ and compute the test statistics using the new series $\{\tilde{y}_{i,t}\}$. Here $\hat{\varepsilon}_{i,t}$ is resampled from the residuals series with replacement. We can repeat this step a number of times and obtain the distribution of the test statistics and therefore the empirical critical values at a given significance level; (3) compare the test statistics with the empirical critical values and make a conclusion regarding the hypothesis.

4. RESULTS AND DISCUSSION

4.1 Panel Unit Root and Panel Cointegration Test

Table 2 shows the Frees (1995) Q statistics and Pesaran (2004) test statistics for both industrial wastewater and SO_2 as the dependent variable. Each column uses one measure of openness in the regression specification; in total, this paper uses three different measures. The test results show that, regardless of which measurement of openness we employ and which type of pollutant we consider, there is a strong indication that the data are cross-sectionally dependent.

Table 2: Cross-Sectional Dependence Test Results

Test	*lnTrade*	*Trade Share*	*lnExport, lnImport*
Pollutant: Industrial Wastewater			
Frees (1995) Q	32.768***	32.783***	32.784***
Pesaran (2004)	4.951***	5.193***	4.633***
Pollutant: SO_2			
Frees (1995) Q	38.409***	37.390***	37.894***
Pesaran (2004)	33.576***	33.574***	31.061***
N	2,610	2,610	2,610

Notes: (1) The null hypothesis of both tests is cross-sectional independence; (2) *** denotes a significance level of 1%; (3) the *Trade share* is (export+import)/GDP; (4) we include the pair of *lnExport* and *lnImport* in the regression as a measure of openness.

Given the interdependence across cities, we apply Pesaran's (2007) CIPS panel unit root test. Table 3 reports the test results for the variables both at levels and after first difference. We consider two specifications, one with only the intercept, the other with both the intercept and the trend pattern. The results show that the variables of $lnWater$, $lnGas$, $lnTrade$, $Trade\ share$, $lnExport$, $lnDensity$, $Manufacturing$, and $Service$ are not stationary at levels but are stationary after first difference. Thus, these variables are integrated of order one. For the other variables—$lnGDP$, $lnGDP\ squared$, $lnImport$, and $lnElectricity$—there is some evidence of stationarity at levels, but they are more stationary after first difference. In general, at the significance level of 1%, we can consider all the variables to be integrated of order one. Consequently, we proceed with the panel cointegration test in the next step.

Table 3: Panel Unit Root Test Results with Cross-Sectional Dependence

	Level		First Difference	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
lnWater	–1.360	–1.951	–2.753***	–3.565***
lnGas	–1.747	–2.189	–2.308*	–2.392
lnGDP	–2.763***	–2.686	–3.132***	–3.405***
lnGDP squared	–2.673***	–2.603	–3.075***	–3.354***
lnTrade	–1.896	–1.900	–2.419**	–2.557
Trade share	–1.888	–2.105	–2.553***	–2.728
lnExport	–1.792	–2.051	–2.700***	–2.856**
lnImport	–2.237*	–2.078	–2.793***	–2.858**
lnElectricity	–2.252*	–2.593	–3.175***	–3.479***
lnDensity	–1.680	–2.271	–2.638***	–2.427
Manufacturing	–2.030	–2.456	–2.822***	–2.666
Service	–1.321	–2.410	–2.978***	–2.983**

Notes: (1) We apply Pesaran's (2007) CIPS test; (2) ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

As explained in the methodology, research prefers Westerlund's (2007) panel cointegration test, which allows for cross-sectional dependence. However, due to the short time span, we cannot apply it in this context. As an alternative, we use the traditional Pedroni (1999; 2004) seven test statistics to test for panel cointegration. We report the two ADF statistics in Table 4, because research has reported that they perform well in a panel with a small time span (Wagner and Hlouskova 2009). As Table 4 shows, we reject the null hypothesis that there is no cointegrating relationship at the 1% significance level in all the specifications of both pollutants. This suggests that, under the assumption that there is no cross-sectional dependence, the seven variables—pollutant, GDP, GDP squared, the openness measure, electricity consumption, population density, and economic structure in terms of the output share of the secondary and tertiary industries—are cointegrated. Subsequently, we estimate the regression equation using different econometric methods that are appropriate under different assumptions.

Table 4: Pedroni's Panel Cointegration Test

	lnTrade		Trade Share	
Pollutant: Industrial Wastewater				
Panel ADF	–17.800***	–22.930***	–18.260***	–24.630***
Group ADF	–19.220***	–29.380***	–21.230***	–31.050***
Pollutant: SO2				
Panel ADF	–18.880***	–23.730***	–17.620***	–26.120***
Group ADF	–21.590***	–29.380***	–20.690***	–31.050***
Obs.	261		261	

Notes: (1) We use the Schwarz information criterion to determine the lag order; (2) *** denotes a significance level of 1%; (3) results are not available for the specification with exports and imports.

4.2 Estimation Results

We first compare the estimation results from the fixed-effect regression, difference GMM, system GMM, and Cup-FM methods. Table 5 reports the coefficient estimates using various methods for the industrial wastewater specification, incorporating the total trade as the measure of openness. Columns 2–3 show the coefficient results from the fixed-effect estimation. We note that the coefficient of $lnGDP$ is positive and the coefficient of $lnGDP\ squared$ is negative, both at a significance level of 10%. This is consistent with the EKC hypothesis, implying that industrial wastewater emissions first increase with economic development and then start to decrease after the GDP reaches a turning point. We can calculate from the fixed-effect estimates of $lnGDP$ and $lnGDP\ squared$ that the turning point appears when the per capita GDP reaches 12,274 yuan (in a constant 2002 price). This is much lower than the turning points that previous studies have found. The coefficient estimates from the fixed-effect regressions are biased because they do not consider the endogeneity and interdependence across units.

In the difference and system GMM estimations in columns 4–7, the lagged dependent variable has a significant and positive impact on the dependent variable $lnWater$, confirming a dynamic relationship. We can reject the AR(1) test but not the AR(2) test, suggesting that the assumption that the residuals are not serially correlated at the second order is satisfied. The Hansen test results show that the second assumption of overidentification restriction is satisfied, suggesting that the instruments are valid. However, the coefficient estimates for $lnGDP$ and $lnGDP\ squared$ using the difference GMM method are insignificant. While the weak instrumental variable problem may be present in the difference GMM estimator (Arellano and Bover 1995; Blundell and Bond 1998), the coefficients of the two GDP variables in the system GMM method are also insignificant, and the signs are even unexpected. The results from both the difference and the system GMM method suggest that the inverted U-shaped EKC is not supported. This is inconsistent with Li, Wang, and Zhao (2016), who used the system GMM estimator for a panel of 28 provinces in the PRC and supported the EKC hypothesis. This is likely to be due to the large N and small T panel and the presence of cross-sectional dependence, because the underlying assumption that the residuals are uncorrelated across units is violated and therefore the results are not reliable.

As explained in the methodology, this paper prefers the CUP-FM estimator, which allows for both endogeneity and cross-sectional dependence. As the last two columns of Table 5 report, all the coefficient estimates are significant at the 1% level. The EKC is well supported, consistent with the findings in the existing literature in the Chinese context (Kang, Zhao, and Yang 2016; Li, Wang, and Zhao 2016). The results imply that there is an inverted U-shaped relationship between wastewater pollution and income for Chinese cities, and we estimate that the turning point happens around 49,446 yuan (in a constant 2002 price). Furthermore, we find that trade reduces the industrial wastewater pollution. Specifically, a 1% increase in the total trade is associated with a 0.04% reduction in wastewater emissions. This may suggest that the technical effect dominates in the trade-environment nexus (Grossman and Krueger 1993).

Next, we utilize the preferred Cup-FM estimator for all the model specifications to examine the relationship between the environment, development, and openness in the PRC as a whole and in different regions of the PRC.

Table 5: Estimation Results from Different Methods

	Fixed Effect		Difference GMM		System GMM		Cup-FM	
	Coefficient	**Robust SE**	**Coefficient**	**Robust SE**	**Coefficient**	**Robust SE**	**Coefficient**	**t-Statistics**
lnGDP	1.111*	(0.670)	0.377	(0.900)	-0.403	(0.369)	1.751***	(11.925)
lnGDP squared	–0.059*	(0.033)	–0.003	(0.045)	0.021	(0.018)	–0.081***	(–10.813)
lnTrade	0.003	(0.037)	0.083	(0.052)	0.039***	(0.012)	–0.044***	(–3.473)
lnElectricity	0.046*	(0.024)	0.018	(0.026)	0.033**	(0.015)	0.044***	(3.675)
lnDensity	0.082	(0.462)	0.294	(0.545)	0.006	(0.014)	–0.684***	(–5.468)
Manufacturing	–0.002	(0.007)	–0.013*	(0.008)	–0.001	(0.002)	0.015***	(6.990)
Service	–0.000	(0.007)	–0.003	(0.005)	–0.005**	(0.002)	0.012***	(5.889)
L.lnWater			0.518***	(0.050)	0.849***	(0.024)		
AR(1)			[0.000]		[0.000]			
AR(2)			[0.369]		[0.332]			
Hansen test			[0.678]		[0.996]			
No. of obs.	2,610		2,088		2,349		2,610	

Notes: The result is for the specification of the pollutant wastewater and variables including *lnGDP, lnGDP squared, openness, lnElectricity, lnDensity, Manufacturing, and Service*; *L.lnWater* is the one year lag of *lnWater*; AR(1) and AR(2) are tests for autocorrelation in differenced residuals; the Hansen test is to test for over-identification restrictions; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

Table 6 reports the Cup-FM estimates of the key variables for various specifications using $lnTrade$, $Trade\ share$, and the pair of $lnExport$ and $lnImport$ as the measure of openness.[3] It is notable that the results support the EKC hypothesis for both pollutants, industrial wastewater and SO_2 emissions. We find that industrial wastewater increases with per capita GDP until it reaches 31,849–49,446 yuan (in constant 2002 prices), depending on which openness measure we consider. As regards the relationship between trade and pollution, as explained earlier, the coefficient estimates suggest that a 1% increase in the total trade is associated with a 0.04% reduction in industrial wastewater. The second model also evidences that trade helps to improve the environment, while the negative coefficient is only significant at the 10% significance level. Birdsall and Wheeler (1993), Ferrantino (1997), and Grether, Mathys, and de Melo (2007) reached similar conclusions. However, it seems that exports and imports alone do not especially matter in reducing industrial water pollution. If we look at the SO_2 emissions, while the EKC hypothesis still holds, the turning point is estimated at around CNY9,274–CNY10,103 per capita income (in constant 2002 prices). On the other hand, we find the total trade to be positively related to SO_2 emissions at the significance level of 5%. Specifically, if the total trade increases by 1%, the SO_2 emissions in that city will tend to increase by 0.03%. This is consistent with the findings of Ang (2009), Jalil and Feridun (2011), and Nasir and Rehman (2011). It should be noted, however, that exports and imports affect SO_2 emissions differently. If the total trade increase is from exports, the SO_2 emissions could be even worse; if the total trade increase is due to an import increase, the SO_2 emissions may be slightly reduced. Partly due to the offsetting effect, we find that the trade share is insignificant, consistent with Li, Wang, and Zhao (2016) using Chinese provincial data.[4]

[3] Due to space considerations, we do not report the results for other control variables, but they are available on request from the authors.

[4] Though not reported, we find that the larger the share of FDI in the GDP, the less polluted water and SO_2 emissions there are in the city, confirming the beneficial impacts of FDI that Huang et al. (2016) discovered.

Furthermore, as expected, the results from the Cup-FM estimation show that wastewater is positively related to electricity consumption. We also observe that the higher the population density, the less per capita polluted water and SO_2. Lastly, the structure of the economy affects the environment as well. A city with a larger share of output from the manufacturing industry tends to produce more wastewater and SO_2 emissions in the production process. A larger share of output from the service industry is associated with more wastewater but fewer SO_2 emissions. This is likely to be because service industries use more water but do not necessarily emit more gas pollutants.

Table 6: Cup-FM Estimation Results

	Pollutant: Industrial Wastewater			**Pollutant: SO_2**		
	(1)	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
lnGDP	1.751***	1.641***	1.659***	1.827***	1.881***	1.783***
	(11.925)	(12.268)	(13.113)	(13.280)	(13.828)	(13.110)
lnGDP squared	–0.081***	–0.076***	–0.080***	–0.100***	–0.102***	–0.097***
	(–10.813)	(–11.008)	(–12.073)	(–13.481)	(–13.940)	(–13.214)
lnTrade	–0.044***			0.031**		
	(–3.473)			(2.230)		
Trade share		–0.086*			0.021	
		(–1.925)			(0.395)	
lnExport			0.001			0.041***
			(0.130)			(4.643)
lnImport			0.004			–0.014*
			(0.660)			(–1.876)
No. of obs.	2,610	2,610	2,610	2,610	2,610	2,610

Note: Other controls include *lnElectricity*, *lnDensity*, *Manufacturing*, and *Service*; ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

4.3 Estimation Results by Region

We repeat the analysis by region. Specifically, we group the cities according to their geographic locations and form three sub-samples. These are East PRC, Middle PRC, and West PRC, which consist of 101, 97, and 63 cities, respectively. Table A1 shows the cross-sectional dependence test results for the three regions in various specifications. Frees' (1995) statistics reject the null hypothesis of independence across cities in all the specifications. Pesaran's (2004) test statistics also reject the null hypothesis in most specifications (except for the specification for wastewater in Middle PRC and the specification for West PRC when we use trade to measure openness). Overall, the test results support the interdependence across cities in East, Middle, and West PRC in the context of the environment, development, and openness.

Next, Table A2 reports the panel unit root test results using Pesaran's (2007) CIPS statistics for all the variables that this paper considers for the three regions. Similar to the tests for the whole PRC, we consider two model specifications (i.e., one with only the intercept, the other with both the intercept and the trend) for the level variable and the differenced variable. We observe that we can reject the null hypothesis that a unit root exists in all the tests when the variables are first differenced and the model contains only the intercept, at least at the significance level of 10%. To conclude, there is strong evidence that all the variables (except $lnGDP$ and $Service$ in East PRC) show the property of integration of order one. Table A3 shows the panel cointegration test results using Pedroni's (1999; 2004) panel and group ADF statistics, which are appropriate when the T is small. Though the test does not consider the cross-sectional dependence, the results at least lend some support to a long-run cointegrating relationship among the variables. Thus, our discussion will subsequently focus on the coefficient estimates that Table 7 reports.

There are two noteworthy findings from Table 7. Firstly, it shows that, regardless of which measure of openness the model employs and which pollutant it considers, the coefficients of $lnGDP$ are all positive and the coefficients of $lnGDP\ squared$ are all negative. Therefore, the results support the EKC hypothesis not only when using city data from the whole PRC but also when using city data from different regions.

Table 7: Cup-FM Estimation Results by Region

	East PRC			Middle PRC			West PRC		
	(1)	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
Pollutant: Industrial Wastewater									
lnGDP	3.181***	2.960***	2.984***	1.439***	1.396***	1.489***	0.794***	0.824***	0.842***
	(11.324)	(13.213)	(10.654)	(3.137)	(3.167)	(3.177)	(5.898)	(6.055)	(5.805)
lnGDP squared	–0.165***	–0.157***	–0.159***	–0.081***	–0.076***	–0.085***	–0.018**	–0.020**	–0.021***
	(–11.754)	(–13.811)	(–11.421)	(–3.451)	(–3.444)	(–3.579)	(–2.342)	(–2.553)	(–2.603)
lnTrade	–0.233***			–0.019			0.008		
	(–9.025)			(–0.952)			(0.381)		
Trade share		–0.037			0.274**			–0.361	
		(–0.868)			(2.275)			(–1.483)	
lnExport			–0.243***			0.014			0.038***
			(–9.258)			(1.136)			(2.932)
lnImport			0.029			0.021**			–0.004
			(1.623)			(2.100)			(–0.309)
Pollutant: SO_2									
lnGDP	1.081***	1.160***	0.899***	2.247***	2.338***	2.240***	1.794***	1.763***	1.822***
	(7.195)	(7.736)	(6.221)	(10.616)	(11.225)	(10.815)	(8.942)	(8.911)	(8.748)
lnGDP squared	–0.049***	–0.054***	–0.036***	–0.118***	–0.121***	–0.115***	–0.100***	–0.098***	–0.101***
	(–5.181)	(–5.858)	(–3.893)	(–11.017)	(–11.427)	(–10.970)	(–8.811)	(–8.652)	(–8.669)
lnTrade	–0.026			0.050***			–0.012		
	(–0.828)			(3.224)			(–0.641)		
Trade share		–0.002			–0.006			0.466**	
		(–0.032)			(–0.058)			(2.230)	
lnExport			0.204***			0.039***			0.057***
			(6.235)			(3.924)			(4.660)
lnImport			–0.129***			–0.052***			–0.032***
			(–5.329)			(–6.658)			(–2.993)
No. of obs.		1,010			970			630	

Note: Other controls include lnElectricity, lnDensity, Manufacturing, and Service.

Secondly, trade has a heterogeneous effect on the environment by region. For industrial wastewater, we find that cities with a high level of openness (in terms of the total trade) are associated with less water pollution in East PRC but more industrial water pollution in Middle PRC. Specifically, the coefficient estimates of $lnTrade$ and $lnExport$ are significantly negative in East PRC, while the coefficients of $Trade\ share$ and $lnImport$ are significantly positive in Middle PRC. This seems to reflect that in East PRC, where the economy is more developed, the environmental regulations are more rigorous, and there are more high-tech industries, trade has a technical and composite effect on the environment in the sense that it helps to reduce the industrial wastewater pollution. On the other hand, in Middle PRC, where the economic structure requires upgrading and there are still some high-polluting industries, trade seems to exhibit a scale effect on the environment, whereby more trade leads to more wastewater pollution. In West PRC, while we find that $lnTrade$ and $Trade\ share$ do not affect the water pollution significantly, we observe that exports have a negative impact on the environment. In the least developed region, the scale effect of trade is likely to dominate. Regarding the results for the pollutant SO_2 emissions, what is striking is that, in all the regions, exports and imports affect the SO_2 emissions in similar ways. More exports tend to increase SO_2 emissions, while more imports tend to decrease SO_2 emissions. Therefore, for the pollutant SO_2, more regulations on the trade industries are necessary.

Table 8: Cup-FM Estimation Results by Openness

	High Openness			**Low Openness**		
	(1)	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
Pollutant: Industrial Wastewater						
lnGDP	2.479***	2.379***	2.404***	–0.160	–0.238	–0.184
	(15.734)	(17.113)	(16.002)	(–0.405)	(–0.596)	(–0.455)
lnGDP squared	–0.130***	–0.131***	–0.128***	0.009	0.015	0.010
	(–15.536)	(–17.234)	(–15.833)	(0.458)	(0.713)	(0.509)
lnTrade	–0.185***			0.011		
	(–9.058)			(0.674)		
Trade share		–0.010			0.804*	
		(–0.248)			(1.884)	
lnExport			–0.110***			0.004
			(–6.236)			(0.465)
lnImport			–0.012			0.019**
			(–0.832)			(2.457)
Pollutant: SO_2						
lnGDP	1.231***	1.667***	1.127***	–0.471	–0.617**	–0.491*
	(12.792)	(11.098)	(11.619)	(–1.787)	(–2.441)	(–1.955)
lnGDP squared	–0.064***	–0.093***	–0.059***	0.013	0.020	0.013
	(–9.981)	(–10.761)	(–9.074)	(0.992)	(1.587)	(1.041)
lnTrade	0.008			0.038***		
	(0.318)			(2.823)		
Trade share		–0.002			1.210***	
		(–0.030)			(3.325)	
lnExport			0.107***			0.039***
			(4.890)			(4.803)
lnImport			–0.050***			–0.028***
			(–2.774)			(–4.262)
No. of obs.		1,310			1,300	

Note: Other controls include lnElectricity, lnDensity, Manufacturing, and Service.

How is trade openness likely to affect our results? To investigate this question, we calculate the city openness index by averaging the trade shares for the period 2004–2013 for each individual city and separate the cities into high-openness and low-openness groups by comparing their openness index with the median. In this way, we obtain 131 cities in the high-openness group and 130 cities in the low-openness group. Table 8 reports the Cup-FM estimation results. It is interesting to find that the EKC hypothesis only holds for the high-openness cities and is invalid for the low-openness cities. Furthermore, as Table 8 indicates, in the sample of high-openness cities, $lnTrade$ and $lnExport$ reduce the industrial wastewater pollution significantly; in the sample of low-openness cities, $Trade\ share$ and $lnImport$ cause the wastewater emissions to diminish. Combining the results with those by region confirms that high openness is associated with less industrial water pollution.

4.4 Granger Causality Results

Lastly, we conduct the panel Granger non-causality test to confirm whether a causal relationship exists. Table 9 presents the results of the panel Granger non-causality test employing Dumitrescu and Hurlin's (2012) method. For the whole of the PRC, it is clearly observable that all the trade openness measures Granger-cause the pollutant variable, be it industrial wastewater or SO_2 emissions. The Granger causal relationship running from trade to the pollutants also holds in East PRC and Middle PRC (except for the pair of *lnTrade* and *lnGas*). In West PRC, we find that only the trade share Granger-causes both pollutants, while there is also some evidence that the total trade Granger-causes industrial wastewater. To conclude, the test generally confirms the Granger causal relationship running from the openness measure to the industrial pollutants, and we should infer the sign of the relationship from the estimation discussed in the last sub-section.

Table 9: Panel Granger Non-Causality Test Results

	The PRC		East PRC		Middle PRC		West PRC	
Test	Test Statistic	p-value	Test Statistic	p-value	Test Statistic	p-value	Test Statistic	p-value
lnTrade→lnWater	3.858	0.000	2.428	0.015	2.5798	0.010	1.5776	0.115
lnTrade→lnGas	10.490	0.000	0.537	0.592	1.1097	0.267	1.9529	0.051
Trade share→lnWater	1.970	0.049	1.846	0.065	2.3250	0.020	7.1891	0.000
Trade share→lnGas	5.999	0.000	2.562	0.010	1.8523	0.064	2.1021	0.036
lnExport→lnWater	6.098	0.000	3.626	0.000	2.1089	0.035	1.0226	0.307
lnExport→lnGas	10.101	0.000	2.600	0.009	4.6078	0.000	0.5059	0.613
lnImport→lnWater	3.756	0.000	10.242	0.000	6.5316	0.000	0.278	0.781
lnImport→lnGas	5.498	0.000	2.840	0.005	6.1030	0.000	1.042	0.298

Notes: (1) The null hypothesis of the Dumitrescu and Hurlin (2012) test is no Granger causality.

5. CONCLUSIONS WITH POLICY RECOMMENDATIONS

This paper has examined the EKC hypothesis and investigated the extent to which trade contributed to the EKC shape across cities over the period 2004 to 2013 in the PRC. To address the criticism of the methodology of the EKC's empirical analysis that some recent studies have raised (Stern 2004; Wagner 2008; Kijima, Nishide, and Ohyama 2010), we adopted an innovative estimation—namely the continuously updated fully modified method—to deal with cross-sectional dependence and endogeneity problems. Compared with fixed-effect regressions and the difference and system GMM estimations, the Cup-FM estimator has good finite sample properties and provides more robust results.

We used industrial wastewater and sulfur dioxide as indicators of environmental pollution, finding that the EKC hypothesis holds not only for the PRC as a whole, but also for different regions of the country. However, the EKC hypothesis only holds for the high-openness cities: it is invalid for the low-openness cities. Cities with higher openness tend to have lower industrial wastewater emissions but higher SO_2 emissions. Specifically, a 1% increase in the total trade is associated with a 0.04% reduction in the industrial wastewater emissions.

The enlarging income gap between the three regions in the PRC and the pollution haven hypothesis have attracted considerable attention. From the perspective of policy design, identification of trade’s impact and the factors that dominate the downturn in emissions will enlighten the pollution-income paths of less developed cities. We may propose the upgrading of the economic structure, the promotion of open economies, and the implementation of strict environmental regulations in less developed and less open cities to achieve sustainable and green economic growth. Moreover, there are two issues that future research needs to address. Firstly, the mechanism behind the fact that the EKC only holds for high-openness cities needs further exploration, and the impact of trade openness on sulfur dioxide emissions calls for more careful modeling of the income-pollution relationship. Secondly, it is possible that downward sloping may arise because of the ‘race to the bottom’ scenario. As more and more ‘dirty’ industries are relocated across regions and within regions in the PRC, and various cities increasingly emphasize the environmental regulations, rich cities might not be able to find poorer cities to serve as a pollution haven in the future, and pollution may again increase. Hence, more fitting models with a longer time horizon are necessary.

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APPENDIX

Figure A1: Geographic Distributions of GDP, Trade Openness, and Pollution (All per Capita)

Figure A1(a): Spatial Distribution of GDP per Capita and Industrial Wastewater per Capita

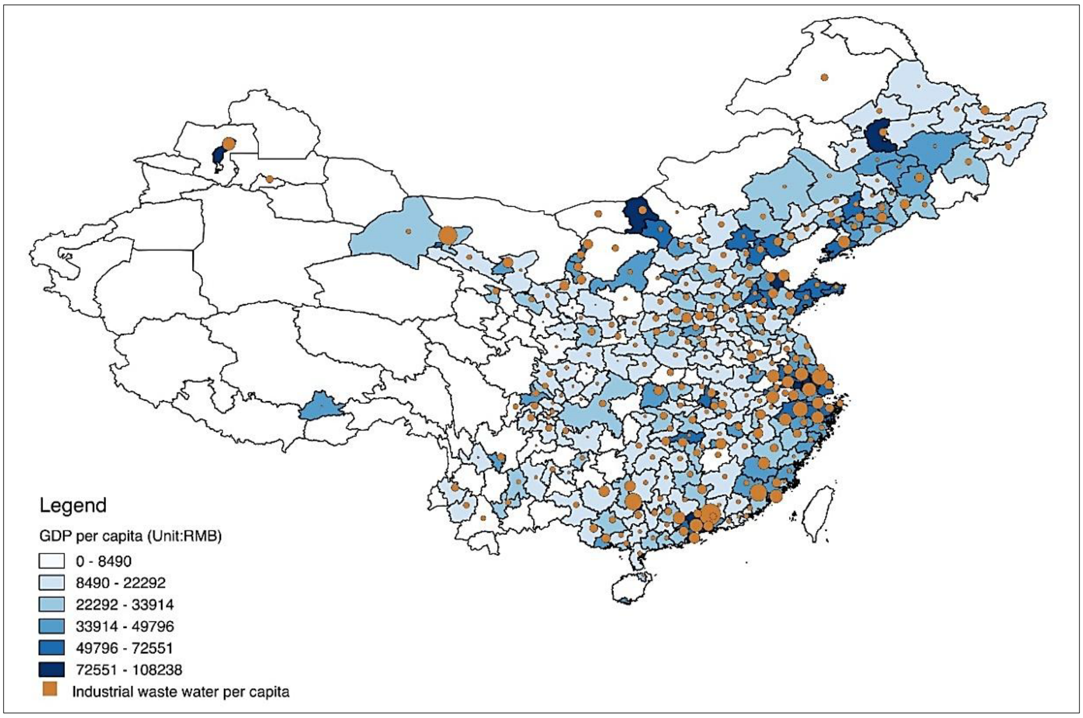


Figure A1(b): Spatial Distribution of GDP per Capita and Industrial SO_2 Emissions per Capita

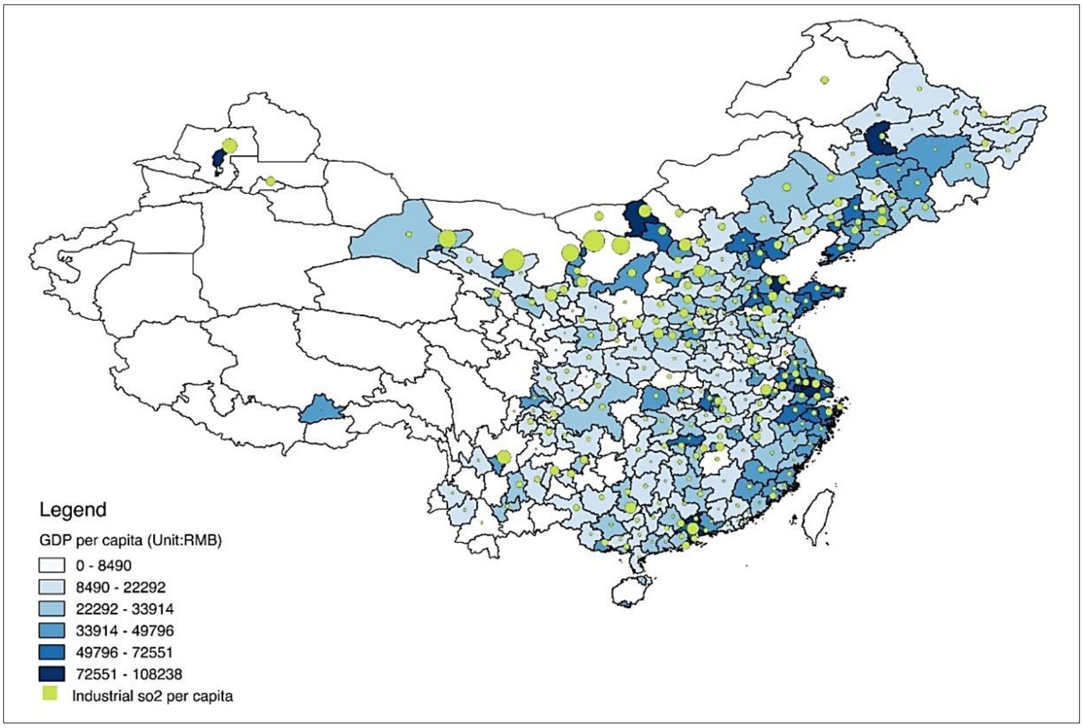


Figure A1(c): Spatial Distribution of GDP per Capita and Trade Openness

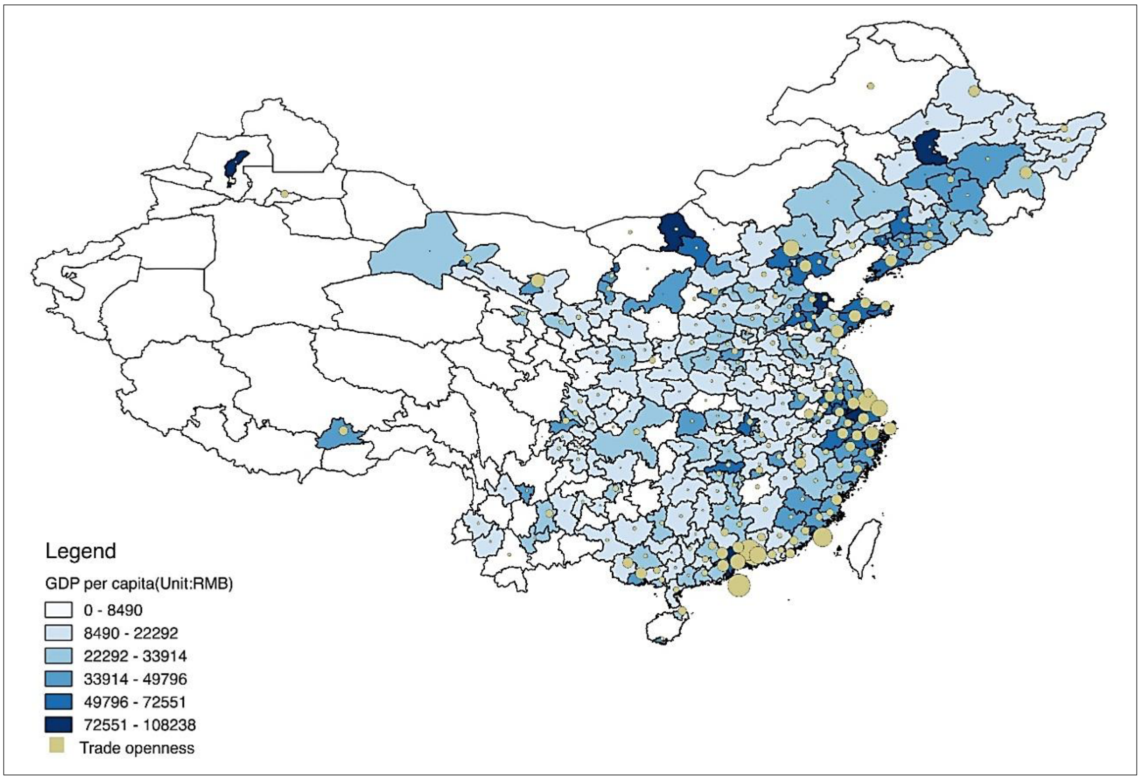


Figure A1(d): Spatial Distribution of Trade Openness and Industrial Wastewater per Capita

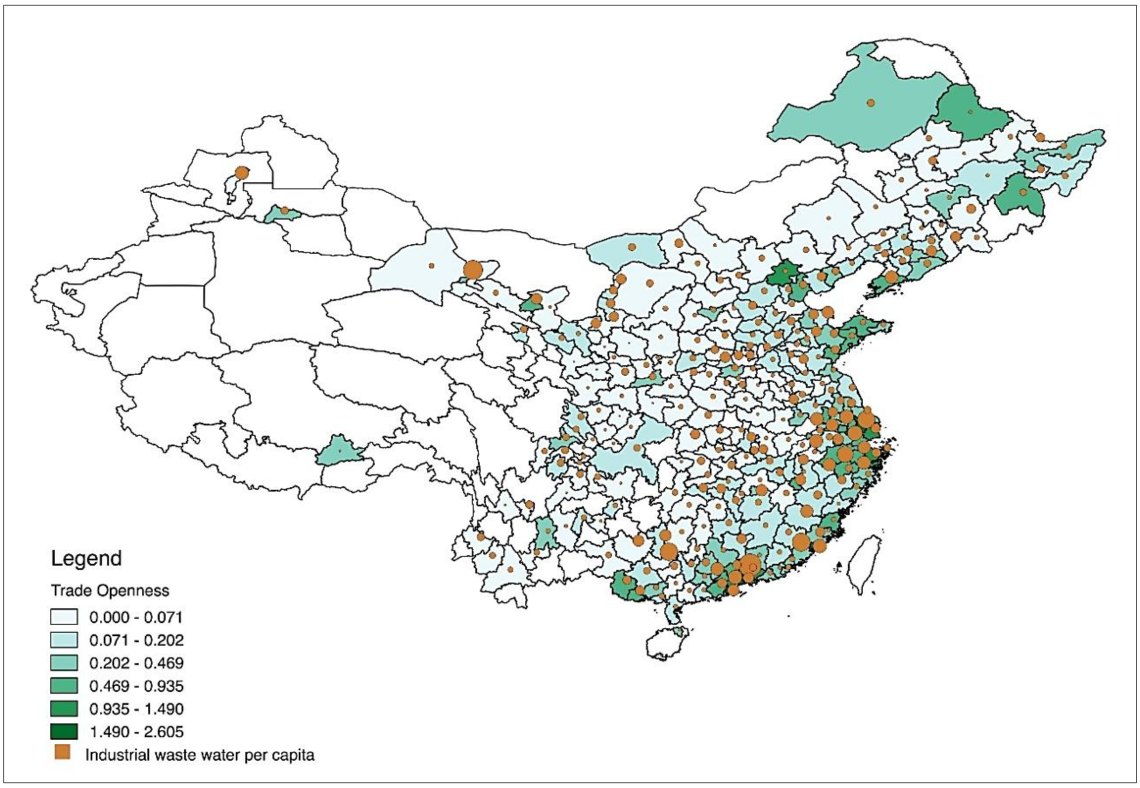
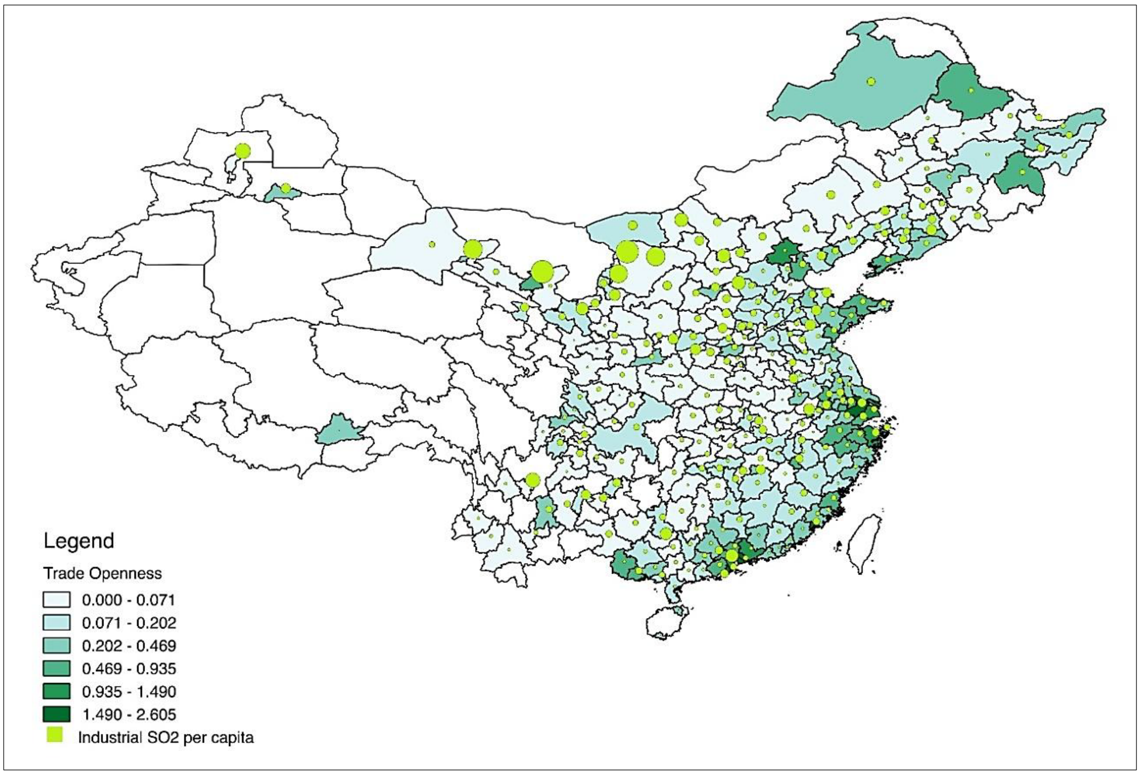


Figure A1(e): Spatial Distribution of Trade Openness and Industrial SO_2 Emission per Capita



Note: The blank cities do not belong to the 261 cities. The figures are drawn based on the average data from 2004 to 2013.

Table A1: Cross-Sectional Dependence Test Results by Region

	Test	*lnTrade*	*Trade Share*	*lnExport, lnImport*
Pollutant: Industrial Wastewater				
East PRC	Frees (1995) Q	11.493***	11.744***	10.262***
	Pesaran (2004)	5.675***	7.406***	7.705***
Middle PRC	Frees (1995) Q	13.275***	13.119***	13.796***
	Pesaran (2004)	0.138	0.143	0.184
West PRC	Frees (1995) Q	5.441***	5.858***	5.502***
	Pesaran (2004)	0.425	0.533	0.393
Pollutant: SO_2				
East PRC	Frees (1995) Q	14.347***	12.792***	14.315***
	Pesaran (2004)	14.066***	14.455***	13.862***
Middle PRC	Frees (1995) Q	10.307***	9.841***	10.966***
	Pesaran (2004)	15.231***	14.443***	12.887***
West PRC	Frees (1995) Q	10.599***	10.058***	9.843***
	Pesaran (2004)	3.922***	3.888***	4.249***

Notes: (1) There are 1010 observations in East PRC, 970 in Middle PRC, and 630 in West PRC for specifications using *lnTrade*, *Trade share*, and *lnExport* and *lnImport* as the openness measure. (2) The null hypothesis of both tests is cross-sectional independence. (3) ***denotes a significance level of 1%.

Table A2: Panel Unit Root Test Results with Cross-Sectional Dependence by Region

		Level		First Difference	
Samples		**Intercept**	**Intercept and Trend**	**Intercept**	**Intercept and Trend**
East PRC	*lnWater*	–1.336	–1.969	–2.636***	–3.403***
	lnGas	–1.655	–2.866**	–2.698***	–2.606
	lnGDP	–3.022***	–3.102***	–3.504***	–3.406***
	lnGDP squared	–2.950***	–2.961**	–3.405***	–3.387***
	lnTrade	–1.871	–1.930	–2.272*	–2.239
	Trade share	–1.861	–2.073	–2.408**	–2.603
	lnExport	–1.651	–1.656	–2.154*	–2.367
	lnImport	–1.939	–1.834	–2.366**	–2.327
	lnElectricity	–2.220*	–2.672	–2.922***	–2.846**
	lnDensity	–1.536	–2.226	–2.640***	–2.811*
	Manufacturing	–1.321	–3.146***	–3.345***	–3.286***
	Service	–2.618***	–3.262***	–3.626***	–3.718***
Middle PRC	*lnWater*	–1.984	–2.264	–2.700***	–3.107***
	lnGas	–1.714	–2.230	–2.322**	–2.123
	lnGDP	–2.711***	–2.637	–2.828***	–2.824*
	lnGDP squared	–2.623***	–2.668	–2.812***	–2.774*
	lnTrade	–1.775	–1.954	–2.580***	–2.861**
	Trade share	–1.726	–2.052	–2.602***	–2.713
	lnExport	–1.661	–1.789	–2.483**	–2.731*
	lnImport	–2.495**	–2.445	–3.246***	–3.342***
	lnElectricity	–2.062	–2.069	–2.935***	–3.328***
	lnDensity	–1.495	–2.360	–2.609***	–2.900**
	Manufacturing	–2.480**	–2.446	–2.915***	–2.701
	Service	–2.387**	–2.394	–2.897***	–2.796*
West PRC	*lnWater*	–2.045	–2.353	–2.719***	–2.001
	lnGas	–2.287*	–2.561	–3.014***	–2.750*
	lnGDP	–2.624***	–2.540	–3.091***	–3.600***
	lnGDP squared	–2.592***	–2.447	–3.026***	–3.570***
	lnTrade	–2.099	–1.879	–2.564***	–2.665
	Trade share	–1.614	–2.215	–2.694***	–3.014**
	lnExport	–2.106	–2.189	–2.881***	–3.063***
	lnImport	–1.929	–1.731	–2.467**	–2.678
	lnFDI	–2.255*	–2.423	–2.893***	–3.139***
	lnDensity	–1.643	–1.970	–2.326**	–2.439
	Manufacturing	–1.954	–2.203	–2.633***	–2.552
	Service	–2.084	–2.322	–2.828***	–2.710

Notes: (1) We apply Pesaran's (2007) CIPS test; (2) ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively.

Table A3: Pedroni's Panel Cointegration Test by Region

	Pollutant: Industrial Wastewater				Pollutant: SO_2			
	lnTrade		Openness		lnTrade		Openness	
East PRC								
Panel ADF	–8.330***	–10.800***	10.400***	–13.900***	–10.400***	–11.800***	–12.400***	–12.000***
Group ADF	–8.650***	–13.400***	–11.100***	–15.800***	–12.600***	–13.400***	–14.000***	–15.800***
Middle PRC								
Panel ADF	–10.300***	–16.500***	–11.200***	–16.700***	–10.200***	–15.500***	–11.500***	–16.300***
Group ADF	–11.100***	–18.700***	–12.300***	–18.600***	–11.900***	–18.700***	–12.600***	–18.600***
West PRC								
Panel ADF	–5.180***	–7.460***	–7.690***	–10.500***	–5.830***	–9.250***	–7.660***	–10.500***
Group ADF	–5.520***	–12.200***	–8.870***	–12.900***	–6.040***	–12.200***	–10.100***	–12.900***

Notes: (1) The Schwarz information criterion determines the lag order; (2) *** denotes a significance level of 1%; (3) the results are not available for the specification with exports and imports.