Environment and Development Economics (2020), **25**, 561–582
doi:10.1017/S1355770X2000042X

RESEARCH ARTICLE

Free trade and the environment – evidence from Chinese cities

Yunzhi Zhang[1,2]*

[1]Department of Economics, Jinan University, Guangzhou, China and [2]LEO, University of Orléans, Orleans, France
*Corresponding author. E-mail: yunzhi.zhang@hotmail.com

(Submitted 1 October 2019; revised 03 June 2020, 26 August 2020, 15 September 2020; accepted 17 September 2020; first published online 20 October 2020)

Abstract
This paper studies the impact of trade openness and the proportion of exporters on environmental quality through the scale, composition and technique effects from 1998 to 2007 using firm- and city-level data for 287 Chinese cities. Our results reveal that, on average, trade openness has a detrimental impact on the environment in Chinese cities, but this impact remains heterogeneous across regions. A higher proportion of exporters improves the environment in central and eastern cities while generating nevertheless more pollution in western cities. As regards the sector-specific impact, we find that the higher proportion of exporters in the mining and less-polluting manufacturing sectors in eastern cities diminishes the emissions of particulate matter 2.5 (PM2.5). Our finding also suggests that a pollution haven effect emerges in China at the city level. Finally, our results confirm the presence of an environmental Kuznets curve effect for the PM2.5 pollutant across Chinese cities.

Key words: China; city-level; environment; firm-level; trade openness

JEL Classification: F18; Q53

1. Introduction

For the past decade, China has been considered the 'world's factory', due to its increasing industrial production and exports of goods to almost all other countries. Indeed, in 2015, *The Economist (2015)* reported that, 'in 1990, China produced less than 3 per cent of global manufacturing output by value; its share is now nearly a quarter. China produces about 80 per cent of the world's air conditioners, 70 per cent of its mobile phones and 60 per cent of its shoes'. However, China's large production output and intense economic activity yields different externalities. On the one hand, China has become the second-largest economy in the world (in terms of GDP), and its economic development depends heavily on exports (i.e., the country is experiencing export-biased growth) (IMF, 2019). On the other hand, its environment might be negatively affected by this rapid economic growth. As shown in figure 1, the growing trend in production is accompanied by an increase in emissions of carbon dioxide and other greenhouse gases. Trade also

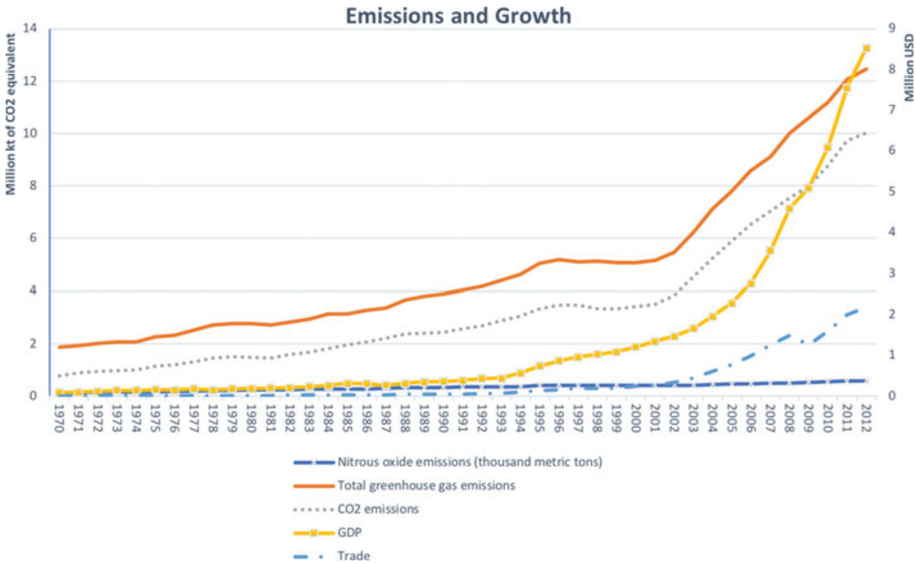

Figure 1. The trend of growth and pollution emissions in China. *Data:* World Bank.

shows an upward trend, which could be similarly related to emissions. Some controversial questions can be raised: does free trade contribute to environmental degradation in China? Do exporters have an impact on pollution? What is the effect of the exporters in different sectors on the environment?

The literature over the last 20 years has viewed trade as closely related to the environment. One strand of the literature discusses the existence of a positive trade–environment nexus. Free trade could contribute to stronger economic growth and increase countries' income levels, thus prompting demands for better environmental quality. Especially, as incomes rise, citizens' consumption preferences can change. People may show a greater interest in consuming environmentally-friendly goods and can demand higher environmental quality. This change would trigger public concern that could further push the government to take measures and design policies aimed at improving environmental quality (Grossman and Krueger, 1991; Antweiler *et al.*, 2001; Frankel and Rose, 2005; among others).

Another strand of the literature holds that trade has an ambiguous impact on emissions (Cole and Elliott, 2003; Chintrakarn and Millimet, 2006; Managi *et al.*, 2009; Korves *et al.*, 2011). Developing countries are assumed to implement more lenient environmental regulation. Within this framework, free trade might induce competition for lax environmental standards in the world market, resulting in the so-called 'race to the bottom'. Otherwise, free trade can attract more foreign investment in the pollution-intensive industries of these countries. This situation may eventually foster a 'pollution haven effect' (PHE).

Regarding China, the existing literature studies different aspects of its integration into the global economy and the impact on the environment. Several papers focus on the effect of foreign direct investment (FDI) (He, 2006; Cai *et al.*, 2016; among others). One such study is that by He (2006), who uses a province-level dataset for the period 1994–2001 and finds that FDI has a small effect on sulfur dioxide (SO_2) emissions. The

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

trade–environment linkage in China has been investigated by Dean (2002); Cole *et al.* (2011), and Poncet *et al.* (2015), among others. For example, based on a sample of 235 Chinese cities from 2003 to 2012, Poncet *et al.* (2015) find that openness has a beneficial impact on the environment in China's case.

Nevertheless, few studies have analyzed the linkage between trade and the environment with respect to exporters. Holladay (2016), controlling for output, finds that exporters pollute less. This analysis only shows the case for a developed country – the US – which might not be the case for emerging and developing countries. The shortage of studies related to the trade–environment nexus at the firm-level points to the need for further evidence. However, information concerning pollution intensity at the firm level is only available for a few countires. Hence, this paper aims to investigate the relationship between trade and the environment by aggregating firm-level data at the city level. In this regard, we complement the literature by putting a focus on the the impact of the increased firms' exports on environmental quality in the case of the emerging country, China.

Our analysis will follow the theoretical framework of Copeland and Taylor (1994, 1995, 2005) to examine the impact of trade on the environment not only through the lens of trade openness, but also with a focus on firms' exports activities. Copeland and Taylor (1994, 1995, 2005) emphasize that trade and economic activity can impact the pollution level through three channels: scale, composition and technique effects. These effects have been widely used to investigate the trade–environment nexus. Specifically, using a sample of 287 Chinese cities over the period from 1998 to 2007, we analyze several dimensions of the impact of trade on the environment: (i) large-scale production of commodities (that is trade-induced); (ii) the composition of economic activities (as the industrial sector, particularly capital-intensive manufacturing industries, has a major presence in China);[1] and (iii) the innovation process and changes in terms of technology. Our analysis focuses first on the full sample of Chinese cities, which can be heterogeneous across regions. Hence, we also divide the cities into three groups according to their geographic location and GDP levels: cities in the western, central and eastern regions. Furthermore, we consider two indicators of the scope of trade: trade openness and the proportion of exporters. We thereby address the following research questions: how does openness affect the environment? Do the exporters increase pollution in China? What is the effect of exporters in different sectors on environmental quality?

Regional disparities in China cause divergences in trade performance (Sawyer *et al.*, 2017). In this analysis, we divide the cities into three groups in terms of their geographic location and economic status. The division is in line with the classification of the National Bureau of Statistics of China.[2]

The first group includes the cities located in the western part of the country, along China's land borders. The landscape varies in this region, and the infrastructure and transportation systems are weak. This region has the lowest GDP level among the three. The second group includes cities located in the central part of China, which are not close to either the land borders or the coast. We include the cities in the northeast in this group. Among the three groups, the cities in the central region are at the medium economic

[1]Capital-intensive industries are considered to be more polluting than other sectors of the economy (Frankel, 2009).

[2]The National Bureau of Statistics of China uses a four-region classification of the cities: in this paper, we use their classification but aggregate two regions that are similar in terms of geographical characteristics, industry composition and economic status.

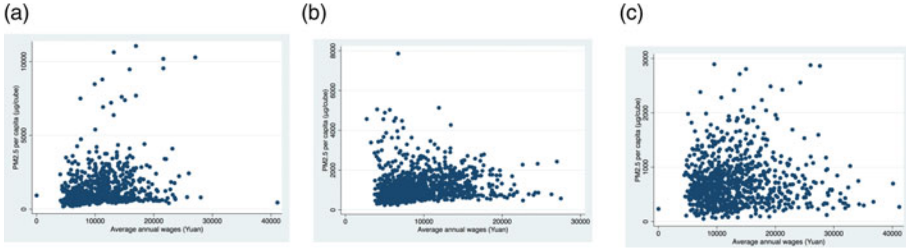

Figure 2. The income–emissions relationships for: (a) the western region, (b) the central region, and (c) the eastern region.

development level. The third group comprises the richest cities which are the coastal cities, located in the east of China. The details of the emissions–income nexus for the three regions (west, center, and east) are shown in figure 2. From the figure, we see that, at the same level of wages, the cities located in the western region have a greater divergence of pollution level than the other regions. This might be due to the smaller population and more pollution-intensive activities. Further descriptive statistics by region are reported in section 4.

The contribution of this paper to the literature is three-fold. First, we analyze the effect of trade on the environment through not only an openness indicator but also by using the proportion of exporters. We obtain this proportion by aggregating the firm-level data. Second, we split the exporters into different sectors by identifying industry compositions and their pollution levels for China's case. Third, we confirm the existence of the environmental Kuznets curve (EKC) effect in China. Our results show that openness in Chinese cities has a detrimental effect on environmental quality, and this effect varies across the regions. Moreover, we find that the effect of export intensity differs across regions. It has a harmful effect on the environment for cities located in the western region, while it has a beneficial impact for the central and eastern cities. These effects mainly happen in some specific sectors.

The remainder of this paper is organized as follows. Section 2 provides the theoretical and empirical literature review for the trade–environment nexus. The model specification and data description are provided in section 3. Section 4 presents the results. In section 5, several robustness checks are reported, and section 6 concludes.

2. Literature review

This section first refers to papers that developed the theoretical framework that can explain the trade–environment nexus through the lens of the scale, technique and composition effects. Second, we present empirical literature on the trade–environment relationship, both at the global level and for the case of China in particular.

At the theoretical level, the pioneering and well-known model of the trade–environment nexus was built by Copeland and Taylor (1994, 1995). Based on a general equilibrium model with a North-South setting, they developed a model in which trade can impact the environment through the channels of the scale, technique and composition effects. First, holding constant the local technique and industries composition, free trade introduces more economic activity. Furthermore, the increased scale of economic activities induces a high intensity of pollution. Second, free trade attracts

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

more multinational firms at the same level of economic scale and with the same composition of industry. Those multinational firms can transfer the clean technologies and efficient management from developed to developing countries. Finally, at the same level of economic scale and technology, countries that have pollution-intensive industries will produce and export 'dirty' goods and have a greater pollution level. In contrast, countries that have less-polluting industries will produce and export 'clean' goods and have a lower pollution level. In the presence of free trade, it allows the transfer of industries and change in the composition of industry for each country.

A large part of the empirical literature investigates the trade–environment nexus. A seminal work on this topic is the research by Grossman and Krueger (1991). Their study was the first to empirically analyze the link between economic growth (as well as trade) and environmental degradation, through the scale, technique and composition effects. According to their findings, the income level has a non-negligible role in explaining this linkage. Using a random effects methodology with cross-sectional data from 42 countries, they find that economic growth raises income levels, but it is detrimental for environmental quality in the early stages of industrial development. However, in a later stage, when the annual income per capita exceeds a certain threshold (set around US$5,000), pollution is reduced as income increases. The relationship thus follows an inverted-U curve, namely, the EKC.

Inspired by the work of Grossman and Krueger (1991) and Copeland and Taylor (1994, 1995), a large part of the empirical literature investigates the trade–environment nexus, and the results of this linkage are inconclusive. Some of the studies confirm the existence of a positive link between trade and the environment (Antweiler *et al.*, 2001; Frankel and Rose, 2005; Managi *et al.*, 2009; Korves *et al.*, 2011; among others). Antweiler *et al.* (2001) applied fixed- and random-effects estimations to a sample of 40 developed and developing countries from 1976 to 1991. Their findings suggest that free trade is good for the environment. This research stresses further the importance of analyzing the scale, technique and composition effects regarding the impact of trade on the environment.

Following Antweiler *et al.* (2001), Kellenberg (2008) investigates the impact of trade on several pollutants by underlining the channel of income level. He examines a cross section of 128 countries for the years 1990 and 1995 and finds that the level of development (namely, income) in each country is crucial in explaining the extent of trade's impact on pollution. The study shows that, when the relative world income is in the range of 0.5–2.5, trade will increase pollutants, and, when the relative income level is outside of this range, trade has a beneficial impact on the environment.

Another well-known study on the trade–environment nexus was conducted by Frankel and Rose (2005). They provide further evidence on the positive relationship between free trade and the environment in a cross-sectional dataset. To solve the endogeneity issue, they employ gravity variables to instrument trade openness. Frankel and Rose (2005) find that trade tends to reduce differently the concentrations of SO_2 and nitrogen dioxide (NO_2), but this effect is ambiguous for particulate matter (PM). They argue that openness has an indirect impact on the environment through economic growth. Moreover, they find evidence that an EKC effect exists in their sample. However, their findings do not find any evidence in support of the pollution haven hypothesis (PHH).

Chintrakarn and Millimet (2006) apply the Ordinary Least Squares (OLS) and Generalized Method of Moments (GMM) approaches to cross-sectional data for different years. By defining a different index based on inter- and intra-state shipments, different measures of emissions are used for each pollutant: emissions at the aggregate level, emissions per capita and emissions per area. Their OLS results show that, although trade has a beneficial effect on the environment, the significance is not consistent for different types and categories of pollutants. Finally, the results of the GMM methodology are generally not statistically significant. However, the authors consider that international trade could not be the main cause of pollution.

Frankel and Rose (2005), Chintrakarn and Millimet (2006), and Kellenberg (2008) find a positive linkage between trade and the environment by using cross-sectional data. This methodology, however, cannot examine the variables across time. More recent studies employ panel data, and some of them find an ambiguous relationship between trade and the environment. Adopting the same instrumental variables (IV) strategy as Frankel and Rose (2005), Managi *et al.* (2009) analyze the direct and indirect impacts of trade on different pollutants. Their data cover 88 countries from 1973 to 2000 for an analysis of the pollutants SO_2 and carbon dioxide (CO_2), and 83 countries from 1980 to 2000 for an analysis of biochemical oxygen demand (BOD) emissions. Their results show that trade has different effects depending on the country and the pollutant. By applying both OLS and fixed-effects analyses, they find that trade openness helps to reduce pollution in the Organisation for Economic Co-operation and Development (OECD) countries. However, in non-OECD countries, trade openness reduces BOD emissions but increases the levels of SO_2 and CO_2 pollutants. Additionally, the authors employ GMM methodology to carry out an in-depth study of the short- and long-term effects. Their results provide evidence that trade has a stronger impact on pollution in the long, rather than the short, term.

The effect of trade on the environment can be heterogeneous according to the different income levels of the countries. Using a sample of 95 developed and developing countries from 1980 to 2004, Korves *et al.* (2011) apply fixed- and random-effects methodologies to panel data to investigate the existence of a PHH for concentrations of sulfur dioxide, carbon dioxide and energy consumption. They do not find support for the PHH in their full sample. Nevertheless, after dividing the sample into different income levels, they capture the presence of a PHE: trade increases pollution in low- and middle-income countries; conversely, it reduces pollution in high-income countries.

More recent research focuses on different issues by approaching the trade–environment nexus using alternative econometric strategies. For instance, Baghdadi *et al.* (2013) use the difference-in-difference (DID) methodology to investigate the impact of free trade on the environment through the channel of regional trade agreements (RTA). By employing a panel dataset of 183 countries from 1980 to 2008, they find that CO_2 emissions converge to similar levels when countries belong to the same RTA, but only when the RTA includes environmental provisions. In their study, they have instrumented the income and openness variables to avoid the endogeneity problem.

Furthermore, the indirect impact of trade on the environment is also investigated. Aller *et al.* (2015) consider that the trade–environment relationship is not only between two countries but also influenced by third trading partners. In this case, the role of the connectivity of the target country can also have an impact on the environment. They measure the connectivity by ranking the degree of 177 countries from 1996 to 2010 with 5 indicators. Applying the three-stage least squares (3SLS) methodology, they find that the indirect effect of trade has a positive impact on environmental quality for low-income countries and a negative impact for high-income countries.

Eskeland and Harrison (2003) employ a sample of five developing countries to study whether there is a pollution haven for multinationals which profit from lax environmental regulations. However, they do not find evidence that foreign investment from developed to developing countries is related to the abatement costs to profit the lax environmental regulations.

A panel quantile regression is employed by Zhu *et al.* (2016) to analyze the effect of FDI, economic growth and energy consumption on carbon emissions. Within the sample of five Association of Southeast Asian Nations (ASEAN) countries from 1981 to 2011, they find that trade and FDI can have a beneficial impact on the environment and that energy consumption is the main source of carbon emissions. Finally, the EKC effect cannot be found in this analysis.

Moreover, some recent studies on the trade–environment nexus are summarized by Afesorgbor and Demena (2019). They conduct a meta-analysis of 88 papers to investigate the impact of trade on the environment. Their findings suggest that trade increases pollution, and this effect is more strongly robust for the CO_2 pollutant than SO_2. They also find that trade has a greater impact on increasing pollution in developed countries, as they are more open than the developing countries.

We focus next on the literature that investigates the trade–environment link for the Chinese case. Given that developing countries tend to attract foreign investment by implementing less stringent environmental policies, Dean (2002) raises a concern about environmental damage following the implementation of free trade in these countries. Her empirical research is developed using provincial-level data on China from 1987 to 1995. The results show that trade liberalization has both a direct and an indirect impact on the environment in China. Overall, Dean (2002) finds that China has a comparative advantage in producing pollution-intensive goods. At the same time, trade liberalization increases income levels in China, positively impacting the demand for better environmental quality.

An interesting research question on China at the city level is raised by Cole *et al.* (2011). They analyze a sample of 112 major Chinese cities from 2001 to 2004 to examine the link between investment/growth and the environment. They use eight environmental indicators as explanatory variables, and they employ lagged income as an IV to avoid endogeneity problems. Most importantly, they identify different investment sources from specific regions of China (Hong Kong, Macao and Taiwan) and from foreign countries to analyze the growth–environment nexus. The results indicate that industrial production can increase pollution in China. This effect is especially induced by domestic firms, and the effect of firms from Hong Kong, Macao and Taiwan is moderate across the pollutants. The environmental effect of foreign investment is different, depending on the pollutants. Their findings also suggest that there is some evidence of the PHE in China.

Moreover, the impact of different trade regimes on the environment in the case of China is studied by Poncet *et al.* (2015). They divide China's trade into ordinary and processing trade regimes to disentangle the different impacts of trade regimes on pollution. Employing fixed effects on a sample of 235 Chinese cities from 2003 to 2012, they also adopt an IV approach to control for the potential endogeneity of the openness variable. Finally, the conclusion of the paper is that openness could have a beneficial effect on the environment – especially the processing trade openness or the trade activity conducted by foreign firms.

Nevertheless, few studies discuss the differential impact of production activities of exporters and non-exporters on pollution. One paper that uses firm-level data to study the relationship between exports, productivity and the environment is that of Cui *et al.* (2012). They develop a Melitz-type model linking the environment and heterogeneous firms with different productivity levels. They employ a fixed-effects estimator to facility-level data for 38,861 observations of the US manufacturing industry in the years 2002, 2005 and 2008. Their empirical results show that, in the same industry, exporters polluted less than non-exporters, for every selling value.

A recent study at the firm level by Holladay (2016) uses plant panel data for the period from 1990 to 2006 to study the impact of exporters and importers on pollution. He applies the fixed-effects method to 12,000–14,000 plant samples and finds that, controlling for output, exporters pollute less than non-exporters. This result is explained by the fact that exporters use new facilities and are more productive.

3. Methodology and data

3.1. Model specification

In this section we provide the specification of the estimated model. In contrast to previous research, we proxy trade levels by not only the degree of openness and but also the proportion of exporters at the city level. We follow the theoretical work of Copeland and Taylor (1994, 1995, 2005) to study how economic activities, trade in particular, can impact environmental quality through three channels: scale, composition and technique effects. We adapt the model to the case of China as follows:

$$\hat{P}_{it} = \hat{S}_{it} + \hat{\varphi}_{it} + \hat{e}_{it} + \hat{\mathbf{Z}}_{it}, \tag{1}$$

where $\hat{P}_{it}$ represents the emissions in Chinese city i in year t. $\hat{S}_{it}$ captures the scale effect. The expansion of economic activities that is induced by trade in China generates more consumption of natural resources, which can further increase the emissions in city i in year t. The **composition effect** is captured by the second term, $\hat{\varphi}_{it}$, representing the output composition. If countries produce a high ratio of pollution-intensive goods, environmental degradation is triggered. However, an environmentally-friendly result can occur if countries produce less-polluting goods. It is not a priori clear what the effect of trade for the case of China is. The third term $\hat{e}_{it}$ in the model indicates the **technique effect**. Multinational firms run operations with innovative technologies and advanced management, and further on trade promotes the entry of these firms and their advantages. Higher level technologies reduce emissions and enable clean industrial production, potentially reducing pollution in China. Moreover, $\hat{\mathbf{Z}}_{it}$ represents other economic controls related to the trade effect on the environment for Chinese cities.

In our model specification, the annual concentration of particulate matter 2.5 (PM2.5) suspended in the air at the city level is the dependent variable used to identify environmental quality. We use this pollutant for two reasons: first, it has the most severe effect on public health in China (Cao *et al.*, 2017); and second, these data are available at the city level.[3]

[3] We are only able to use PM2.5, because data for other emission indicators are not available at the city level for the period under study.

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

Including further control variables, our final specification is given by:

$$\begin{aligned} EmissionDen_{it} = {} & \beta_0 + \beta_1 (industry/GDP)_{it} + \beta_2 (K/L)_{it} \\ & + \beta_3 ln(FDI_{it}) + \beta_4 Trade_{it} \\ & + \beta_5 ln(Wage_{it}) + \beta_6 ln(EleComsumption_{it}) + \varepsilon_{it}, \end{aligned} \quad (2)$$

where $ln(.)$ denotes the natural logarithm. The dependent variable ($EmissionDen_{it}$ in the regression) is the emissions of PM2.5 per square km in city i in year t.

We include income ($Wage_{it}$ in the regression) as an explanary variable in our analysis, to capture the **scale effect** (Copeland and Taylor, 2005; Cole *et al.*, 2011, Baghdadi *et al.*, 2013; among others).

The **composition effect** is captured by the share of the industrial output to GDP ($(industry/GDP)_{it}$ in the regression) in our analysis as in previous studies (He and Richard, 2010; Aller *et al.*, 2015; among others). As China is a manufacturing country, emissions in the secondary sector are considered to be the main source of China's pollution.

We further control for the **technique effect** by including foreign direct investment (FDI_{it} in the regression) in our specification. The role of investment in determining the pollution level has been identified by Cole *et al.* (2011). Since multinational firms have advanced technologies and efficient management in clean production, they bring these advantages with them when they invest/relocate in developing countries, with a beneficial impact on environmental quality. This finding is also confirmed by the study of Zhu *et al.* (2016) who find that FDI helps to reduce carbon emissions, especially in low- and middle- income countries. A contrasting hypothesis is discussed by Antweiler *et al.* (2001); namely that FDI could harm the environment. Specifically, this theory is the PHH: multinational firms run their operations in countries with lax environmental policies to relocate pollution-intensive industries there, in order to have a lower abatement cost.

Poncet *et al.* (2015) employ the ratio of capital to labor as a further control to investigate the impact of factor endowment on emissions. Other studies such as Managi *et al.* (2009) and Cole and Elliott (2003) also include this variable in their model to examine the trade–emission nexus. We follow their method to measure the factor endowment ($(K/L)_{it}$ in the regression) for Chinese cities.

Energy consumption is also considered as the main source of emissions, as proven in the previous literature (Cole *et al.*, 1997; Poncet *et al.*, 2015; Zhu *et al.*, 2016; among others). We proxy the energy consumption by using the consumption of electricity ($EleComsumption_{it}$ in the regression) in each Chinese city for each year.

We use two variables to proxy trade intensity and evaluate the impact of trade on pollution in this study. The first variable is the annual trade openness index at the city level, and the second is the proportion of exporters in each city for each year. The openness index, computed as the trade intensity (the ratio of the sum of exports and imports to GDP) in city i in year t, is included as $Openness_{it}$ in our specification.

Furthermore, we use a second variable, $Exporter_{kit}$, in our analysis: the ratio of exporting firms to total firms in city i in year i. We consider this rate in two stages. First, we include the proportion of exporters in order to understand whether the increasing exporters can affect the environmental quality of Chinese cities. A high ratio of exporters to total local firms shows the city's trade intensity, captured at the plant level. Holladay (2016) claims that, for the same level of output, exporters pollute less than non-exporters.

Thus, we hypothesize that, at the same GDP level, cities with more exporters may have lower emissions. Therefore, the exporters in different industries might be the source for this link. To study this aspect in more depth, we divide exporters by different industrial sectors (mining, pollution-intensive manufacturing, less-polluting manufacturing, and electricity sectors). These rates are computed as follows:

$$Exporter_{kit} = \frac{X_{kit}}{N_{kit}}, \tag{3}$$

where $Exporter_{kit}$ is the proportion of exporters in sector k in city i in year t; X_{kit} denotes the number of exporting plants in sector k in city i in year t; and N_{kit} is the total number of firms in sector k in city i in year t.

Finally, we split the industrial sectors into four different categories according to their emissions. The pollution information about major industrial emissions data for 41 industries in China is shown in figures A1 and A2 in the online appendix. The emissions related to industrial smoke dust for each manufacturing industry are reported in figure A1. The most polluting industries in this regard are: non-metallic manufacturing; electricity, heating production and supply; smelting and pressing ferrous metal manufacturing; chemical manufacturing; petroleum, coal and other fuel processing; and non-ferrous metal manufacturing. The emissions of industrial solids are reported in figure A2, indicating substantial emissions in some industries: electricity, heating production and supply; smelting and pressing ferrous metal manufacturing; coal and mining industry; ferrous metal mining industry; and non-ferrous metal mining industry. From the information above, we identify the following as pollution-intensive manufacturing industries: paper manufacturing; petroleum, coal and other fuel processing; chemistry manufacturing; non-metallic mining manufacturing; smelting and pressing ferrous metal manufacturing; and smelting and pressing non-ferrous metal manufacturing.[4] Combining the pollution information, we can further divide the industries that are included in the secondary sectors into four categories: the pollution-intensive manufacturing sector, the less-polluting manufacturing sector, the mining sector and the electricity sector. Last, we calculate the rate of exporters introduced above for each of these categories separately. These variables are $ExpoterMin_{it}$, $ExpoterMaPo_{it}$, $ExpoterMaNonpo_{it}$, and $ExpoterEle_{it}$ for the proportion of exporters in the mining, pollution-intensive manufacturing, less-polluting manufacturing and electricity sectors, respectively.

An endogeneity problem with the income variable is also mentioned in the previous literature. For instance, potential endogeneity issues are raised by income–environmental policy and the income–trade link (Frankel and Rose, 2005; Baghdadi *et al.*, 2013, among others). To avoid this issue, we adopt an IV strategy by employing a set of variables to mitigate the endogeneity by following the measure of Baghdadi *et al.* (2013).[5] Finally, the instruments that we adopt in this paper are the one-year lagged of income, population and the enrollment rates of primary school and university students.

[4]Shen *et al.* (2017) consider that the following industrial sectors are pollution-intensive: mining and quarrying; production and supply of electric power; gas and water; paper making and paper products; non-metal mineral products; smelting and pressing of ferrous metals products; manufacture of chemicals; and smelting and pressing of non-ferrous metals.

[5]Baghdadi *et al.* (2013) employ a set of variables to control this: 'lagged income, population, investment, and human capital formation'.

3.2. Data

The data used cover the period from 1998 to 2007. Three levels of data are employed: pollution data, city-level administration data and firm-level data. They are drawn from different datasets. Descriptive statistics are presented in table 1. The correlation information for the data can also be found in table A1 (online appendix).

Our data on the pollutant PM2.5 are taken from the Socioeconomic Data and Applications Center (SEDAC), which is managed by the NASA Earth Science Data and Information System project.[6] The emission measurement used in this paper is the annual concentration of the PM2.5 value in 287 Chinese cities. It consists of annual concentrations (micrograms per cubic meter) of ground-level fine particulate matter (PM2.5), with dust and sea salt removed.

The prefecture-level data on 287 Chinese cities are drawn from China's City Statistic Yearbook. The variables available at this level include GDP, population, city area, investment, education and wage. City name and location information (western, central and eastern regions) are shown in table A2 (online appendix). Moreover, the data on the total volume of trade (the sum of the export and import values) are drawn from the Local Statistical Yearbook in each city. We compute the ratio of the sum of the export and import values to GDP by combining these two datasets.

Precise industry data are not available at the city level. We aggregate the firm-level data in order to proxy the city-level industry data. These firm data are drawn from the annual surveys from the Chinese National Bureau of Statistics. This dataset includes the firms in China that have total sales of more than 5 million Chinese Yuan, which is the so-called 'above-scale'. These data include a four-digit Chinese Industry Classification (CIC) code, as well as location, export value, founding year and value-added, for each of these firms. Data on the number of different firms in each city in each year are drawn and aggregated from this level.

4. Empirical results

This section reports the empirical results for the impact of trade on the environment for Chinese cities. We include both fixed and random effects to estimate the model. In the meantime, we also employ an IV strategy by instrumenting the income variable to avoid the potential endogeneity issues. In this analysis, we include proxies for free trade in two ways. First, we use a variable for openness, which is also considered as the level of trade and the intensity of trade activities. Then, we investigate the role of exporters with regard to the environment. To that end, we apply the proportion of exporters for each Chinese city in each year in two stages. We calculate the ratio of the total number of exporters to the total firms, and then we compute the proportion of exporters in the mining, pollution-intensive manufacturing, less-polluting manufacturing, and electricity sectors. To separate the specific nature of regional disparity in China, we therefore set three dummies to represent the different regions of China in our model. The first dummy is for the region that includes the cities located in the western part of the country. The second one includes cities located in the central part of China. The richest region, which encompasses the cities located across coastal China, is captured by our third dummy.

[6]See the website at http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-gwr-pm2-5-modis-misr-seawifs-aod (Van Donkelaar *et al.*, 1998).

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

Table 1. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
$EmissionDen_{it}$	2,616	31.5184	16.89367	2.345798	286.0162
$(industry/GDP)_{it}$	2,694	45.02325	11.45669	9	89.72
$(K/L)_{it}$	2,622	0.1278733	0.098446	0.0015895	1.515343
$ln(FDI_{it})$	2,524	8.404669	2.037401	0.6931472	13.47399
$Openness_{it}$	2,025	0.0328808	0.0970538	1.32×10^{-6}	3.326589
$Exporter_{it}$	2,803	0.8056781	0.1301	0	1
$MinExporter_{it}$	1,513	0.7615609	0.2791715	0.0015723	1
$PoExporter_{it}$	2,610	0.9222105	0.1605288	0.0172414	1
$NonpExporter_{it}$	2,735	0.9582879	0.1186423	0.0243902	1
$EleExporter_{it}$	729	0.7084935	0.302041	0.0040323	1
$ln(EleComsumption_{it})$	2,664	12.08751	1.217304	7.717796	16.18798
$ln(Wage_{it})$	2,633	9.216502	0.4750724	2.283402	11.82836
$(lnWage_{it-1})^2$	2,633	85.16952	8.424319	5.213926	139.9101
West					
$(industry/GDP)_{it}$	724	42.54068	13.47503	9	89.72
$(K/L)_{it}$	689	0.1104616	0.0758294	0.0015895	0.7662484
$ln(FDI_{it})$	592	6.951183	1.875435	0.6931472	12.1261
$Openness_{it}$	366	0.0095853	0.0145907	1.32×10^{-6}	0.2042151
$Exporter_{it}$	820	0.8869556	0.071994	0.5714286	1
$ln(EleComsumption_{it})$	711	11.6367	1.235302	7.717796	15.05647
$ln(Wage_{it})$	691	9.239538	0.4930521	2.283402	11.82836
Central					
$(industry/GDP)_{it}$	1,111	44.47721	11.01025	15.7	89.7
$(K/L)_{it}$	1,084	0.1038576	0.0664061	0.004878	0.3540253
$ln(FDI_{it})$	1,077	7.946658	1.646429	2.484907	12.62295
$Openness_{it}$	911	0.0114205	0.0207043	0.000026	0.1831941
$Exporter_{it}$	1,118	0.833354	0.1045218	0.5	1
$ln(EleComsumption_{it})$	1,100	11.96534	1.063224	8.633375	14.63182
$ln(Wage_{it})$	1,086	9.081774	0.3997949	7.906547	10.22165
East					
$(industry/GDP)_{it}$	859	47.8219	9.418412	20.44	82.28
$(K/L)_{it}$	849	0.1726668	0.1290949	0.005507	1.515343
$ln(FDI_{it})$	855	9.987992	1.474819	6.018593	13.47399
$Openness_{it}$	748	0.0704162	0.1505239	0.0013143	3.326589
$Exporter_{it}$	865	0.6928582	0.1259013	0	0.9512195
$ln(EleComsumption_{it})$	853	12.62083	1.195046	9.562826	16.18798
$ln(Wage_{it})$	856	9.368836	0.4990296	2.712042	10.62592

(*continued*)

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

Table 1. Continued.

Variable	Obs	Mean	Std. Dev.	Min	Max
Variables used in the robustness section					
$Avmining_{it}$	2,164	0.1311319	0.1927683	−0.0035216	0.9786752
$AvMapo_{it}$	2,230	0.2578006	0.154866	−0.0629956	0.9906114
$AvManonpo_{it}$	2,232	0.4473397	0.2284743	0.0018998	1
$AvElec_{it}$	2,221	0.1161893	0.1059972	−0.7289789	0.7524124

Notes: The data for each region is also reported in the table. West, Central, and East refers to the data for the cities located in the western, central, and eastern regions.

In the next subsections we present separate results for the two target variables used, namely, openness in 4.1 and export intensity in 4.2, interacting in each case the corresponding target variable with regional dummies.

4.1. Openness

Table 2 reports the results for the impact of openness on emissions. We first employ fixed effects by controlling for the city- and time-invariant impact. These results are shown in the first two columns. Column (1) reports the results for the full sample of Chinese cities. The positive sign of the openness variable suggests that the high intensity of trade activities has a detrimental effect on the environment by increasing emissions of PM2.5. The magnitude of the coefficient indicates that a one-unit increase in openness, ceteris paribus, would lead to an average increase of 31.17 $\mu g/m^3$ of PM2.5 in every square km for the cities in China. The region-specific openness effects are reported in column (2). From these results, we find that the detrimental impact of trade mainly happens in the cities of the western region, since only those cities show that trade has a statistically significant effect on environmental quality. The coefficient indicates that a one-unit increase in openness, all else being equal, would lead an increase of 39.32 $\mu g/m^3$ of PM2.5 in every square km for the cities located in the western region on average. As a comparison, we then perform the random effects by including year dummies within our model, and the results are shown in columns (3) and (4).[7] Column (3) reports the results for all Chinese cities on average. The coefficient for openness shows a negative sign, nevertheless, it is insignificant. We observe that, when we count for the region-specific openness effect, as the results show in column (4), the variables for the three regions all have negative signs. However, only the coefficient for the cities in the eastern region is statistically significant. This result indicates that, all else being equal, a unit increase in openness would reduce PM2.5 per square km by 337 $\mu g/m^3$ on average for cities in the eastern region of China. Columns (5) and (6) show the result of the estimation that controls for the income variable by using the IV strategy. Although all the tests show the validity of the instrument, the results for the full sample show that the coefficient for openness in column (5) is not statistically significant. The results for the openness effect in different regions are reported in column (6). The coefficients for the western and the central regions are not statistically significant. Openness has a beneficial impact on the environment for the cities located in the eastern region. The magnitude of coefficient indicates that, all else

[7] A Hausman test has been run to investigate which method is more reliable. The results allowed us to choose the fixed-effects model rather than the random-effects one.

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

being equal, a unit increase in openness in the eastern region would reduce an average of 258.3 $\mu g/m^3$ of PM2.5 per square km. All in all, we find that trade openness has a detrimental impact on environmental quality, which is different from the conclusion of Poncet *et al.* (2015). However, a recent study by Afesorgbor and Demena (2019) finds that most of the papers reach a conclusion that trade increases pollution, and this impact can vary depending on different pollutants.

The other controls have the expected signs and are statistically significant overall. For the variable that captures industry composition, the positive signs show that the higher the proportion of industrial output to total domestic output, the more polluted is the environment. The factor endowment, which is proxied by the ratio of capital to labor, is also positive. This result indicates that those cities that are relatively endowed with capital have higher emissions. Turning to the results for FDI, they are positive and statistically significant when fixed and random effects are employed. The positive signs for FDI might prove the existence of the PHE for Chinese cities. The low cost of production regarding the environmental policy or technology standards in China attracts foreign investment; thus, these multinationals do not have the positive impact of improving the local environment. This result is in line with the research of Cole *et al.* (2011). Furthermore, when we control for fixed effects, the coefficient of electricity consumption is negative, which could be explained by the fact that the consumption of electricity is not the main source of PM2.5 emissions. Finally, the coefficients for the wage are positive, which means that the environment deteriorates as the local income level increases.

4.2. The impact of exporters

In the previous subsection, we show that openness can have a detrimental impact on the environment for Chinese cities, on average, and this effect is heterogeneous across regions. We suppose that a city's specialization in a sector, such as manufacturing, might have a more detrimental impact on the environment than the other sectors. Hence, it is interesting to analyze how exporters could affect environmental quality.

Exporters can have a different impact on the environment compared to local firms (Holladay, 2016). In this subsection, the proportion of exporters is used to evaluate the impact of trade on emissions from the perspective of firms. We first compute the ratio of number of exporters to total firms for each Chinese city using the industrial firm-level data (in the secondary sector) and then split exporters into different sectors k in city i in year t.

Table 3 reports the impact of the proportion of exporters on environmental quality at the city level. Columns (1), (3), and (5) report the results from employing respectively the fixed-effects, random-effects and IV methodology for the full sample of Chinese cities. However, the coefficients for $Exporter_{it}$ in these columns show no statistical significance. When we focus on the region-specific exporters effects, we find the heterogeneous effects among regions. These results are shown in columns (2), (4) and (6). The second column reports the impact of the proportion of exporters on the environment by controlling the time and city fixed effects. The coefficient of exporters shows a positive sign for those cities located in the western region, which indicates that, when the proportion of exporters in the western region is higher, so are emissions in the region. Meanwhile, the coefficient of the proportion of exporters of the central region has a negative sign, meaning that more exporters in this region can reduce the local emissions of PM2.5. The effect in the eastern region does not show any statistical significance. The results across regions by applying random effects and including the year dummies are reported

Table 2. The impact of openness

	(1)	(2)	(3)	(4)	(5)	(6)
$(industry/GDP)_{it}$	0.369*** (0.073)	0.363*** (0.073)	0.204*** (0.0568)	0.197*** (0.0564)	0.540** (0.184)	0.529*** (0.2)
$(K/L)_{it}$	25.38*** (5.331)	24.91*** (5.335)	16.31*** (4.863)	14.24** (4.895)	−2.955 (14.19)	−3.025 (24.14)
$ln(FDI_{it})$	0.678* (0.342)	0.703* (0.343)	1.198*** (0.29)	1.151*** (0.289)	−2.236 (1.372)	−2.171 (1.354)
$Openness_{it}$	31.17* (13.58)		−14.05 (9.972)		17.41 (38.73)	
$ln(EleComsumption_{it})$	−2.420* (1.001)	−2.550* (1.003)	−0.0809 (0.642)	0.152 (0.637)	−0.466 (2.692)	−0.837 (2.639)
$ln(Wage_{it})$	7.654*** (1.34)	7.716*** (1.339)	3.756** (1.298)	3.792** (1.298)	122.1+ (65.48)	121.2+ (64.71)
$Openness_{west}$		39.32** (14.2)		−13.87 (10.05)		30.44 (39.32)
$Openness_{center}$		−28.07 (35.93)		−42.04 (31.19)		−81.32 (60.25)
$Openness_{east}$		−94.01 (123.7)		−337*** (98.63)		−258.3+ (149.4)
N	1,866	1,866	1,869	1,869	1,774	1,776
City FE	yes	yes	no	no	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
RE	no	no	yes	yes	no	no
Hausman test	56.82		80.87			
Hausman (*p*-value)	0		0			
Underidentification test					34.439	34.419
Weak identification test					15.411	15.517
Hansen J test (*p*-value)					0.459	0.4363

Notes: Robust standard errors in parentheses.
***, **, *, + denote significance at the 0.1, 1, 5 and 10% level, respectively.
Dependent variable : the concentration of PM2.5 per square kilometer in city *i* in year *t*.
The underidentification test is based on an LM version of the Anderson (1951) canonical correlation test and its *p*-value (Chi-sq(4)) is less than 0.1, indicating that the test rejects the null hypothesis that the equation is underidentified. The weak identification test is based on the Cragg-Donald Wald F statistic. The F-statistic is above 10, which indicates the validity of the instrument. The Sargan-Hansen test is the overidentification test of all instruments. The *p*-value (Chi-sq(3)) is greater than 0.1, meaning that the instruments are valid; otherwise, the instruments would not be valid.

in column (4). The coefficient for the cities in the western region shows a positive sign, which indicates that more exporters in this region can increase emissions. Then, the sign of coefficient for exporters in the central region is statistically insignificant. The effect of the eastern region shows a beneficial impact on the environment. Finally, the result of an estimate that instruments the income variable is reported in column (6). In this case, the coefficients on the exporters for the three regions are not statistically significant. All in all, the high proportion of exporters in cities located in the western region has a harmful impact on the environment. Moreover, having more exporting firms in the central and eastern regions can reduce the emissions in these areas.

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

Table 3. The impact of exporters

	(1)	(2)	(3)	(4)	(5)	(6)
$(industry/GDP)_{it}$	0.246*** (0.0624)	0.224*** (0.0623)	0.169*** (0.0493)	0.145** (0.0486)	0.308 (0.275)	0.279 (0.278)
$(K/L)_{it}$	23.76*** (4.723)	23.62*** (4.705)	21.32*** (4.439)	19.58*** (4.435)	−16.59 (30.17)	−17.58 (30.54)
$ln(FDI_{it})$	0.513+ (0.27)	0.509+ (0.269)	1.01*** (0.234)	0.566* (0.243)	−4.354 (2.834)	−4.322 (2.814)
$Exporter_{it}$	2.877 (3.806)		1.155 (3.318)		−25.15 (20.85)	
$ln(EleComsumption_{it})$	−1.289 (0.813)	−1.426+ (0.811)	0.248 (0.543)	-0.232 (0.540)	6.302 (5.464)	6.000 (5.375)
$ln(Wage_{it})$	2.892** (0.918)	2.984** (0.915)	1.191 (0.896)	1.337 (0.893)	153.3 (97.76)	152.4 (97.32)
$Exporter_{west}$		21.23*** (5.754)		9.652* (3.924)		0.267 (17.29)
$Exporter_{center}$		−9.803+ (5.164)		4.745 (3.346)		−32.9 (21.87)
$Exporter_{east}$		−22.35 (16.27)		−6.291+ (3.542)		−125.7 (113.0)
N	2,430	2,430	2,436	2,436	2,278	2,278
City FE	yes	yes	no	no	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
RE	no	no	yes	yes	no	no
Hausman test	97.07		100.82			
Hausman (*p*-value)	0		0			
Underidentification test					3.41	3.258
Weak identification test					7.097	7.088
Hansen J test (*p*-value)					0.5672	0.6396

Notes: Robust standard errors in parentheses.
***, **, *, + denote significance at the 0.1, 1, 5 and 10% level, respectively.
Dependent variable : the concentration of PM2.5 per square kilometer in city *i* in year *t*.
The underidentification test is based on an LM version of the Anderson (1951) canonical correlation test and its *p*-value (Chi-sq(4)) is less than 0.1, indicating that the test rejects the null hypothesis that the equation is underidentified. The weak identification test is based on the Cragg-Donald Wald F statistic. The F-statistic is above 10, which indicates the validity of the instrument. The Sargan-Hansen test is the overidentification test of all instruments. The *p*-value (Chi-sq(3)) is greater than 0.1, meaning that the instruments are valid; otherwise, the instruments would not be valid.

Exporters have an uncertain impact on the environmental quality, on average, for the full sample of Chinese cities. Moreover, this effect varies across the regions. To examine the impact of exporters in more depth, we split the industries into four sectoral categories by using firm-level data. Doing so provides us with further information on exporters' environmental performances across industries. We assume that if there are more exporters in 'dirty' sectors, the region has a comparative advantage in producing 'dirty' goods. Eskeland and Harrison (2003) discuss how foreign investors prefer to invest in those countries with a low cost of the factors they need, which means that foreign investment/exporting firms might have preference for pollution-intensive or

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

less-polluting sectors. Hence, it could be of interest to investigate the impact of exporters in different sectors. These results are reported in table 4. The variables in this estimation – $MinExporter_{it}$, $PoExporter_{it}$, *NonpExporter* and *EleExporter* – capture the ratio of exporters to total firms in the mining, pollution-intensive manufacturing, less-polluting manufacturing and electricity sectors, respectively. The coefficients are not statistically significant for the full sample of Chinese cities, and they do not show any statistical significance for cities in the central region, although they do show such significance for cities located in the western and eastern regions. For cities in the western region, the results show that a higher proportion of exporters in the less-polluting manufacturing sector increases the local emissions of PM2.5. Regarding the results of the eastern region, the variables show that more exporters in the mining sector could mitigate the emissions. Furthermore, exporters in the less-polluting manufacturing sector can have a larger positive impact on environmental quality than the other sectors, as the magnitude of the coefficient shows.

5. Robustness

In this section, we perform three robustness checks to corroborate our results. First, we use an additional variable, income squared, to test for the presence of the EKC effect. For the second robustness check, we include value-added variables for each secondary industry. Finally, we also consider another methodology concerning the endogeneity issue.

5.1. The environmental Kuznets curve

As the first robustness check, we include income squared in the regressions to examine the nonlinear relationship between income and pollution. In the previous section, we highlighted the importance of the income effect, which is also linked to the EKC. Again, this relation is that, at the early stage of development, pollution increases as income increases. Once the local income reaches a certain amount (which varies across countries), called a turning point, emissions decrease when income increases due to an awareness in society of the importance of environmental protection. Nevertheless, the EKC effect does not necessarily exist in the case of all pollutants. For example, Carson (2010) finds that there is no EKC effects for the emissions of CO_2; Bradford *et al.* (2005) confirm this finding by examining several emissions.

To understand whether there is an EKC effect on PM2.5 for Chinese cities, we include an additional variable, wage squared. Our model is as follows:

$$EmissionDen'_{it} = \beta_0 + \beta'_1(industry/GDP) + \beta'_2(K/L)_{it} + \beta'_3 ln(FDI_{it}) + \beta'_4 Trade_{it} + \beta'_5 ln(Wage_{it}) + \beta'_6(lnWage_{it-1})^2 + \beta'_7 ln(EleComsumption_{it}) + \varepsilon'_{it} \quad (4)$$

The results of testing for an EKC effect for Chinese cities are shown in tables A3 and A4 (in the online appendix). Table A3 shows the impact of openness on environmental quality, which allows us to test whether the EKC effect is present in China. In columns (1), (2) and (3), we include fixed and random effects, and use an IV strategy, respectively. Focusing on the variables of wage and its square term, we find an EKC effect for Chinese cities, since the coefficients of wage report positive signs and its squared terms are negative for three cases. These results indicate an inverted-U curve for the income-emissions

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

Table 4. The impact of the exporters' rate in the four sectors

	(1) FE	(2) RE	(3) IV
All sample			
$MinExporter_{it}$	−1.023 (1.483)	−1.192 (1.482)	−1.792 (1.532)
$PoExporter_{it}$	−9.469 (10.75)	2.073 (10.27)	−8.401 (11.16)
$NonpExporter_{it}$	2.735 (11.82)	10.33 (11.75)	1.377 (13.58)
$EleExporter_{it}$	0.496 (1.199)	0.693 (1.21)	0.561 (1.219)
Western region			
$MinExporter_{it}$	−3.83 (4.536)	−1.642 (7.039)	−7.301 (5.56)
$PoExporter_{it}$	−15.55 (23.24)	58.24 (35.76)	−7.262 (27.49)
$NonpExporter_{it}$	−2.778 (47.95)	101.2+ (59.57)	−35.74 (66.98)
$EleExporter_{it}$	3.316 (4.16)	2.42 (6.685)	10.53 (7.119)
Central region			
$MinExporter_{it}$	0.606 (2.167)	−0.0674 (2.103)	1.355 (2.266)
$PoExporter_{it}$	1.164 (14.26)	12.61 (13.0)	−3.73 (15.21)
$NonpExporter_{it}$	1.736 (12.78)	7.236 (12.57)	−8.391 (15.07)
$EleExporter_{it}$	-0.052 (1.964)	-0.358 (1.934)	0.0459 (2.049)
Eastern region			
$MinExporter_{it}$	−3.096+ (1.764)	−2.836 (1.895)	−3.095+ (1.787)
$PoExporter_{it}$	−22.44 (19.84)	−32.33 (21.44)	−25.7 (20.66)
$NonpExporter_{it}$	−176.3* (80.78)	−136.5 (85.77)	– –
$EleExporter_{it}$	1.335 (1.229)	1.234 (1.330)	1.641 (1.267)

Notes: Robust standard errors in parentheses.
***, **, *, + denote significance at the 0.1, 1, 5 and 10% level, respectively.
Dependent variable : the concentration of PM2.5 per square kilometer in city *i* in year *t*.

relationship. The EKC effect, shown through the impact of exporters on emissions, is shown in table A4. Using the same method as in table A3, columns (1), (2) and (3) of table A4 report the results of the fixed effects, random effects, and IV estimations of our regression, respectively. The results also show that the coefficients for the wage term are

https://doi.org/10.1017/S1355770X2000042X Published online by Cambridge University Press

positive, and those for its squared term show a negative sign. From these results, we cannot reject the EKC hypothesis for Chinese cities concerning PM2.5 emissions. Finally, the impact of trade on environmental quality is in line with the baseline results.

5.2. Additional variables

Some additional variables can be interesting to include to control for scale and manufacturing size. We use a set of additional variables in our second robustness check. As argued by Cherniwchan *et al.* (2017), the value-added produced by firms can be translated into the scale of industry output. We aggregate the value-added data at the firm level for the four industrial sectors classified in this paper. The results are shown in tables A5 and A6 of the online appendix.

Table A5 reports the results of our specification by adding the value-added produced in different industrial sectors, through the impact of openness on the environment. However, the openness variable shows a significance only in column (1), when we include fixed effects. This result confirms the detrimental impact of openness on environmental quality for Chinese cities as in our baseline results. The results employing random effects and IV methodology are presented in columns (2) and (3); they are not statistically significant. Furthermore, the additional variables are $Avmining_{it}$, $AvMapo_{it}$, $AvManonpo_{it}$ and $AvElec_{it}$, representing the value added in the mining, pollution-intensive manufacturing, less-polluting manufacturing and electricity sectors, respectively. The variables of value-added produced in the mining and pollution-intensive manufacturing sectors do not show statistical significance. Meanwhile, the coefficients of $AvManonpo_{it}$ and $AvElec_{it}$ report negative signs. This result indicates that the higher value-added produced in the less-polluting manufacturing and electricity sectors can improve environmental quality in terms of PM2.5 emissions for Chinese cities.

The results of adding the value-added variables to investigate the impact of exporters on PM2.5 emission are presented in table A6. We study this issue by including the fixed and random effects, as well as implementing an IV strategy; the results are reported respectively in columns (1), (2), and (3). As in our baseline results, the impact of exporters remains inconclusive, as they do not show any statistical significance. Regarding the additional variables, the coefficients of $AvManonpo_{it}$ and $AvElec_{it}$ report negative signs, which have the same results as in table A5.

5.3. Endogeneity issue

Although we have controlled the endogeneity of the income variable, some argue that the variable of trade should be instrumented as well. As Frankel and Rose (2005), Managi *et al.* (2009) and Baghdadi *et al.* (2013) argue, another endogeneity issue arises between trade and income since trade increases the income levels; conversely, citizens with higher incomes will demand more exports and imports. The general strategy is to control the income variable by using the growth model and the trade variable with the gravity model. Since the interregional data for the Chinese case are lacking, we follow the studies of Chintrakarn and Millimet (2006) and Managi *et al.* (2009) to employ a GMM estimation by employing the method of Arellano and Bond (1991). We instrument both the income and trade variables by using their lags. The results are reported in table A7. The first column shows the results of the impact of trade openness on the environment. The coefficient for openness is negative but it is not statistically significant. The impact of the exporters is reported in column (2). The coefficient for exporters shows also a negative sign and insignificance. Precise information regarding the sector is provided in column (3). The only significant value for the less-polluting manufacturing sector shows that a larger proportion of exporters in this sector increases the PM2.5 emissions for Chinese cities. For the other controls, the results are not always statistically significant. The corresponding tests indicate that first order autocorrelation is present in the data, whereas second order autocorrelation is not, as expected in this setting. Regarding the Hansen tests, they cannot reject the null hypothesis that the instruments are valid according to the results in columns (2) and (3) in table A7.

6. Conclusions

We use firm- and city-level data from 1998 to 2007 to analyze the impact of trade on the emissions of PM2.5 in China. Following the theoretical framework of Copeland and Taylor (1994, 1995, 2005), this paper emphasizes the impact of trade on the environment through not only the openness channel but also the proportion of exporters at the city level. The results show that openness has a detrimental impact on the environment, specifically on the emissions of PM2.5. However, this impact remains heterogeneous across regions. It seems that openness has a detrimental impact on the environment for the cities located in the western region, but a beneficial impact for the cities located in the eastern region. The results of the impact of exporters show no influence on the environment. Therefore, the results vary across the regions in China: the high proportion of exporters in the cities located in the western region has a harmful impact on the environment. And more exporting firms in the central and eastern regions can reduce the emissions in these areas. We further investigate this effect by dividing exporters into four sectors in an effort to capture their pollution levels. The results show that, for cities located in the western region, the higher the fraction of total firms which are exporters in the less-polluting manufacturing sector, the greater the local emissions of PM2.5. Therefore, the higher proportion of exporters in the mining and less-polluting manufacturing sectors for the cities in the eastern region has a greater beneficial impact on the environmental quality.

There are a number of policy implications to be drawn from this paper. First, trade has a heterogeneous impact on the environment for Chinese cities. This finding indicates that the Chinese government should adopt different strategies across its regions to reduce pollution. For instance, trade has a detrimental impact on the environment for cities located in the western region. Meanwhile, for the cities in the eastern region, trade can diminish emissions of PM2.5. Furthermore, our results suggest the existence of a pollution haven effect for the case of Chinese cities. Finally, our results confirm the presence of an EKC. As China is still at the early stage of the curve (income increases as the emissions increase), measures to raise awareness about environmental protection are also important for the public.

Finally, one limitation of this paper is that it accounts only for PM2.5 concentrations when analyzing the impact of trade on the environment. Environmental regulation at the local level is an additional factor that should also be included in further analyses of the trade–environment nexus. As these data are not available at the city level in China's case, the aforementioned questions represent open avenues for further research.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X2000042X.

Acknowledgments. I am grateful to the anonymous referees and the invited editors for their constructive and valuable comments and suggestions that helped me to greatly improve the quality of this paper. I would like to thank Camėlia Turcu, Bogdan Ianc, Zhe Dai, Zhaojing Ni for their helpful remarks. Many thanks to the participants at the INFER conference for insightful comments on this paper.

References

Afesorgbor SK and Demena BA (2019) The effect of trade on the environment: evidence from meta-analysis. *2019 Annual Meeting, Agricultural and Applied Economics Association, 21–23 July, Atlanta, GA*.

Aller C, Ductor L and Herrerias MJ (2015) The world trade network and the environment. *Energy Economics* **52**, 55–68.

Anderson TW (1951) Estimating linear restrictions on regression coefficients for multivariate normal distributions. *Annals of Mathematical Statistics* **22**, 327–351.

Antweiler W, Copeland BR and Taylor MS (2001) Is free trade good for the environment?. *American Economic Review* **91**, 877–908.

Arellano M and Bond S (1991) Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies* **58**, 277–297.

Baghdadi L, Martinez-Zarzoso I and Zitouna H (2013) Are RTA agreements with environmental provisions reducing emissions?. *Journal of International Economics* **2**, 378–390.

Bradford DF, Fender RA, Shore SH and Wagner M (2005) The environmental Kuznets curve: exploring a fresh specification. *Contributions in Economic Analysis & Policy* **4**, article 5 1–28.

Cai X, Lu Y, Wu M and Yu L (2016) Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. *Journal of Development Economics* **123**, 73–85.

Cao Q, Liang Y and Niu X (2017) China's air quality and respiratory disease mortality based on the spatial panel model. *International Journal of Environmental Research and Public Health* **14**, 1081, https://doi.org/10.3390/ijerph14091081.

Carson RT (2010) The environmental Kuznets curve: seeking empirical regularity and theoretical structure. *Review of Environmental Economics and Policy* **4**, 3–23.

Cherniwchan J, Copeland BR and Taylor MS (2017) Trade and the environment: new methods, measurements, and results. *Annual Review of Economics* **9**, 59–85.

Chintrakarn P and Millimet DL (2006) The environmental consequences of trade: evidence from subnational trade flows. *Journal of Environmental Economics and Management* **52**, 430–453.

Cole MA and Elliott RJ (2003) Determining the trade–environment composition effect: the role of capital, labor and environmental regulations. *Journal of Environmental Economics and Management* **46**, 363–383.

Cole MA, Rayner AJ and Bates JM (1997) The environmental Kuznets curve: an empirical analysis. *Environment and Development Economics* **2**, 401–416.

Cole MA, Elliott RJ and Zhang J (2011) Growth, foreign direct investment, and the environment: evidence from Chinese cities. *Journal of Regional Science* **51**, 121–138.

Copeland BR and Taylor MS (1994) North-South trade and the environment. *The Quarterly Journal of Economics* **109**, 755–787.

Copeland BR and Taylor MS (1995) Trade and transboundary pollution. *The American Economic Review* **85**, 716–737.

Copeland BR and Taylor MS (2005) *Trade and the Environment: Theory and Evidence*. Princeton, NJ: Princeton University Press.

Cui J, Lapan HE and Moschini G (2012) Are exporters more environmentally friendly than non-exporters? Theory and evidence. Economics Working Papers (2002–2016), Iowa State University Working Paper #12022. Available at https://lib.dr.iastate.edu/econ_las_workingpapers/77/.

Dean JM (2002) Does trade liberalization harm the environment? A new test. *Canadian Journal of Economics/Revue Canadienne d'É conomique* **35**, 819–842.

Economist The (2015) Made in China. *The Economist*, 12 March 2015. Available at https://www.economist.com/leaders/2015/03/12/made-in-china.

Eskeland GS and Harrison AE (2003) Moving to greener pastures? Multinationals and the pollution haven hypothesis. *Journal of Development Economics* **70**, 1–23.

Frankel JA (2009) Environmental effects of international trade. HKS Faculty Research Working Paper Series, RWP09-006, John F. Kennedy School of Government, Harvard University.

Frankel JA and Rose AK (2005) Is trade good or bad for the environment? Sorting out the causality. *Review of Economics and Statistics* **87**, 85–91.

Grossman GM and Krueger AB (1991) Environmental impacts of a North American free trade agreement. NBER Working Paper No. 3914, National Bureau of Economic Research, Cambridge, MA.

He J (2006) Pollution haven hypothesis and environmental impacts of foreign direct investment: the case of industrial emission of sulfur dioxide (SO_2) in Chinese provinces. *Ecological Economics* **60**, 228–245.

He J and Richard P (2010) Environmental Kuznets curve for CO_2 in Canada. *Ecological Economics* **69**, 1083–1093.

Holladay JS (2016) Exporters and the environment. *Canadian Journal of Economics/Revue Canadienne d'Économique* **49**, 147–172.

IMF (2019) People's Republic of China: 2019 article IV Consultation. IMF Country Report No. 19/266. International Monetary Fund, Asia and Pacific Department. Available at https://www.imf.org/en/Publications/CR/Issues/2019/08/08/Peoples-Republic-of-China-2019-Article-IV-Consultation-Press-Release-Staff-Report-Staff-48576.

Kellenberg DK (2008) A reexamination of the role of income for the trade and environment debate. *Ecological Economics* **68**, 106–115.

Korves N, Martínez-Zarzoso I and Voicu AM (2011) Is free trade good or bad for the environment? New empirical evidence. In Blanco J and Kheradmand H (eds), *Climate Change – Socioeconomic Effects*. Rijeka, Croatia: InTech, pp. 1–30.

Managi S, Hibiki A and Tsurumi T (2009) Does trade openness improve environmental quality?. *Journal of Environmental Economics and Management* **58**, 346–363.

Poncet S, Hering L and Sousa JD (2015) Has trade openness reduced pollution in China? Ferdi Working Paper P132, Fondation pour les Études et Recherches sur le Développement International (FERDI), Clermont-Ferrand, France.

Sawyer WC, Tochkov K and Yu W (2017) Regional and sectoral patterns and determinants of comparative advantage in China. *Frontiers of Economics in China* **12**, 7–36.

Shen J, Wei YD and Yang Z (2017) The impact of environmental regulations on the location of pollution-intensive industries in China. *Journal of Cleaner Production* **148**, 785–794.

Van Donkelaar A, Martin RV, Brauer M and Boys BL (1998) Global annual PM 2.5 grids from MODIS. MISR and SeaWiFS Aerosol Optical Depth (AOD), 2012. Available at https://catalog.data.gov/dataset/global-annual-pm2-5-grids-from-modis-misr-and-seawifs-aerosol-optical-depth-aod-1998-2012-cb442.

Zhu H, Duan L, Guo Y and Yu K (2016) The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression. *Economic Modelling* **58**, 237–248.

Cite this article: Zhang Y (2020). Free trade and the environment – evidence from Chinese cities. *Environment and Development Economics* **25**, 561–582. https://doi.org/10.1017/S1355770X2000042X