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Has trade openness reduced pollution in China?*

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Abstract

We use recent detailed Chinese data on trade and pollution emissions to assess the environmental consequences of China's integration into the world economy. We rely on a panel dataset covering 235 Chinese cities over the 2003-2012 period to see whether the environmental repercussions from trade openness depend on whether the latter concerns processing or ordinary activities. In line with our theoretical predictions, we find a negative and signicant effect of trade on emissions that is larger for processing trade and activities undertaken by foreign firms: the environmental gains from either ordinary trade activities or domestic firms are much lower, even though these today represent the main drivers of China's export and import growth. This result suggests some caution regarding pollution prospects in the context of the declining role of processing trade.

Key words: Trade openness, pollution, SO2 emissions, China.

JEL Codes : F10, F14, O14.

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1 Introduction

Over the past twenty years environmentalists and the trade-policy community have engaged in a heated debate over the environmental consequences of liberalized trade.[1] China, by becoming a world-class exporter and experiencing serious environmental degradation, has helped intensify this debate. The pollution-haven hypothesis, whereby firms strategically (re)locate their pollution-intensive activities in countries with the lowest environmental standards or weakest enforcement, predicts that China, as a developing country, has been made dirtier by trade (Taylor, 2004). By way of contrast, Dean and Lovely (2010) suggest that Chinese exported goods have become less pollution-intensive over recent years, which could have positive repercussions on the local environment.[2] The empirical challenge of properly identifying the causal effect of trade on pollution has led to a lack of consensus on the environmental consequences of Chinese trade.

In this paper, we investigate the links between trade openness and pollution emissions in Chinese cities. We use sub-national trade data, differentiating between processing and ordinary trade,[3] as well as between trade by domestic and foreign-owned firms to account for the role of trade in intermediates in determining the environmental consequences of the internationalization of the largest country in the world. Our empirical analysis appeals to

[1]For an earlier review of the arguments see Copeland and Taylor (2004).

[2]The authors calculate the pollution intensity of imports and exports using industrial sector-level emissions intensity. This pollution intensity is then weighted by the share of manufacturing exports (imports) corresponding to that sector and summed to yield an export (import)-weighted average pollution intensity for each year.

[3]Processing trade refers to operations of firms, most often foreign, which obtain raw materials or intermediate inputs from abroad and, after assembling them in China, reexport the value-added final products (Feenstra and Hanson, 2005). Operations in the assembly sector that import inputs to process them in China and re-export the final products account for 41% of China's trade between 2002 and 2012. Moreover, a considerable share of this assembling-trade, roughly 84% over the period, comes from foreign-invested enterprises.

panel data covering 235 Chinese cities from 2003 to 2012. We focus on Sulfur Dioxide (SO_2) emissions, which are considered to be one of the major sources of air pollution[4] in China, and ask how greater trade liberalization affects emission intensity.

First, we build on the existing theoretical literature that has described the different channels, of opposing signs, via which trade growth affects pollution (Antweiler, Copeland, and Taylor, 2001; McAusland and Millimet, 2013) and propose additional effects that are specific to the trade in intermediates. The theoretical model which forms the basis for our analysis extends the frameworks in Ethier (1982) and Krugman and Venables (1995) to account for the environmental consequences of local production and assembling of intermediates. We identify two mechanisms, splitting the impact of trade liberalization on pollution into productivity and displacement effects. These mechanisms account for the specificity of Chinese trade, the structure of which is rather dualistic between processing and ordinary activities. The specificity of processing activities pertains to their use of both imported and local intermediates. In a setting where local pollution emanates from domestic production activities, greater trade openness encourages processing firms to substitute imported intermediates for local (polluting) inputs. However, this substitution reduces the production cost of the intermediates and leads to productivity gains that increase emissions through a larger scale of production. This theoretical ambiguity on the effect of trade, which is common in the environmental literature (see e.g. Antweiler, Copeland, and Taylor, 2001; McAusland and Millimet, 2013), calls for empirical research. Our empirical finding of a negative and significant effect of processing trade on emissions is consistent with the displacement effect, i.e. what Levinson (2009) calls "pollution displaced by imports".

[4]Data on water pollution are unfortunately not available at the city level for our time span.

Second, our empirical approach extends recent efforts to address endogeneity issues, which in general hinder the evaluation of the impact of trade on the environment (Frankel and Rose, 2005; Managi, Hibiki, and Tsurumi, 2009).[5] Trade openness and the way in which trade policy is designed and enforced are likely to be correlated with other policies, including environmental policies and a variety of broader economic variables. For example, foreign direct investment has been identified in the literature as a driver of both trade and environmental performance.

To deal with the potential endogeneity issues, we depart from the traditional use of cross-sectional data across a diverse set of countries, and exploit spatial and temporal heterogeneity in trade and pollution within a single country. China is particularly well-suited for such analysis, as it is characterized by considerable internal variations in both the level and the growth rate of trade and pollution emissions. Focusing on one single country has a number of advantages compared to cross-country analysis. First, it mitigates omitted-variable problems related to the difficulty of controlling for cross-country differences in national policies, legal systems and other institutions. Second, it reduces the traditional empirical difficulty that the environmental effects of trade are conditional on how local comparative advantage and environmental regulatory stringency compare to those in the rest of the world. Finally, it avoids the data-compatibility problems that are present in most cross-country analyses, as countries may not define, collect, and measure trade and pollution variables consistently.[6]

[5] A large literature exists on the link in the opposite direction from the environment or environmental policies to trade, and faces the same empirical challenge (Grossman and Krueger, 1993; Levinson and Taylor, 2008; Broner, Bustos, and Carvalho, 2012).

[6] Two notable exceptions are McAusland and Millimet (2013) and Chintrakarn and Millimet (2006), which use data on intra-national and international trade for Canadian provinces and/or US states. They mostly focus on the differential effects of inter-regional versus international commerce. Our approach differs in that we focus on the largest developing country in the world. Also our data allows us to highlight the role of the international segmentation of production.

Our work here also contributes to the literature in two other dimensions. Our first contribution relates to the focus on China, and sheds light on the strain its emergence in the world market has placed on the environment. China is the poster child for air pollution. Its greenhouse-gas emissions were about 10% of the world's total in 1990, but close to 30% in 2013 (The Economist, 2013). China has the world's highest annual incidence of premature deaths triggered by air pollution, which is estimated to represent a loss of about 3.8% in its yearly GDP (World Bank, 2007). As the fastest-growing economy over the past fifteen years, China has become the world's biggest trader in goods, overtaking the US in 2013; understanding the environmental repercussions of China's rise to dominance in world trade is thus key to understanding how to tackle pollution issues both in China and worldwide. Our results suggest that trade has had a beneficial effect on the Chinese environment. This is in line with the most recent cross-country studies that have made use of exogenous determinants of trade to identify the causal effect of trade on the environment (Frankel and Rose, 2005; Chintrakarn and Millimet, 2006; Managi, Hibiki, and Tsurumi, 2009). This estimated impact is robust to alternative indicators of pollution and more demanding specifications in terms of controls. From a quantitative point of view, the size of the effect is not negligible. A 1 percentage point increase in trade openness is estimated to have led to a fall in SO_2 emissions per capita of 0.7%.

Second, we highlight the role of trade regimes in the trade-environment nexus. A growing literature has underscored the many ways in which processing and ordinary trade regimes differ, and the implications of these regimes for China (Brandt and Morrow, 2013). The most fundamental difference between ordinary and processing activities, which is captured in our model, is in terms of domestic value-added. Koopman, Wang, and Wei (2012) and

Kee and Tang (2015) calculate that the domestic value-added embodied in a dollar of exports is half as high for processing than for ordinary exports. Technological content is an additional difference. Foreign firms,[7] which are typically engaged in processing-trade activities, have driven the skill-content upgrading of China's manufacturing exports (Amiti and Freund, 2010; Xu and Lu, 2009). These firms have higher productivity and produce higher product quality than do domestic firms (Ge, Lai, and Zhu, 2015), in line with the well-known finding that foreign ownership leads to significant productivity gains (Bloom, Sadun, and Van Reenen, 2012; Arnold and Javorcik, 2009).[8] Furthermore, processing trade appears to be associated with higher-quality varieties than is ordinary trade (Wang and Wei, 2010). Last, since processing trade involves high-quality imported inputs being further processed in China, with the finished goods being exported, processing activities are likely to use more technologically-advanced techniques and strict quality control and verification compared to ordinary activities that involve lower-quality domestic inputs.

An open question is then whether trade expansion affects the environment differently when carried out under ordinary or processing regimes. Our theoretical model highlights the ambiguity in the productivity and displacement effects related to processing trade. Two other ambiguous factors, not considered in our model, may also affect emissions: (1) processing trade may produce technical change, prompting the use of cleaner production techniques (the so-called technique effect in Antweiler, Copeland, and Taylor, 2001) (2) the limited domestic embeddedness of processing activities is often viewed as limiting their contribution

[7] Here and in the rest of the paper, we define "foreign firms" as those with some foreign-capital ownership (i.e., wholly foreign-owned firms as well as joint ventures; the latter includes equity and non-equity joint ventures and joint cooperatives).

[8] The superior performance of foreign affiliates typically derives from international technology spillovers (Keller and Yeaple, 2009) and fewer financial constraints (Arnold and Javorcik, 2009; Manova, Wei, and Zhang, 2015).

to economic growth (Jarreau and Poncet, 2012), which may also limit the demand for more stringent environmental regulation accruing from processing trade.

By differentiating empirically between processing and ordinary trade, as well as foreign and domestic trade, we build on the recent literature on the particularities of foreign-owned firms and processing trade (Amiti and Freund, 2010) and investigate whether production fragmentation plays a role in the environmental repercussions of China's enhanced outward orientation. Our results reveal a positive and significant effect of trade on emissions that is mostly attributable to processing trade and activities undertaken by foreign firms:[9] much lower gains result from either ordinary trade activities or domestic firms, even though these have been the main contributors to the growth in China's trade over the last decade.[10] This result is consistent with the finding in Dean and Lovely (2010) of a positive link between China's pollution intensity and FDI or processing activities.[11]

The remainder of the paper is structured as follows. The next section outlines the theoretical framework for the link between processing trade and the environment, and Section 3 sets out our empirical strategy. Section 4 then presents the data and some descriptive statistics while Section 5 discusses the results. Last, Section 6 concludes.

[9] In the robustness checks, we calculate trade openness using domestic value-added in trade to ensure that our results are not driven by different levels of local value-added content.

[10] In 2002, ordinary trade represented 42.7 percent of China's total trade, but this share rose to 44.5 percent by 2007, and by 2012 had reached 52.1 percent.

[11] Our work differs in that we exploit city-level data and compute exogenous sources of city-level trade openness, which provide us with an original instrumental-variable approach to address the endogeneity problems that are typical in this area.

2 A simple model of processing trade and the environment

In this section we present a simple model that identifies the specific channels through which processing trade affects the environment. The specificity of processing trade pertains to its use of imported intermediates as well as local intermediates. In our setting, domestic pollution emanates from local production activities (of final and intermediate goods). Our focus is on how trade liberalization modifies this source of pollution.

To answer this question we analyze the demand and supply of local and imported intermediates in the manufacturing sector using a monopolistic-competition model à la Ethier (1982), which we modify to account for the environmental consequences of local production. We make three assumptions to keep things simple. First, we consider that each firm produces a single variety, which can be consumed as an intermediate or a final good. This simplification implies that "manufacturing uses manufacturing as an input" (Krugman and Venables, 1995).[12] Second, we assume that production uses labor, energy and both local and foreign intermediates. By using energy as an input, pollution is a by-product of producing a variety. Third, we adopt a partial-equilibrium approach and do not model the consumer demand for final goods. We instead focus on how trade liberalization affects the polluting local production of intermediates.

We consider the two-country case, Home and Foreign, which are identical in endowments, preferences, and technology. We now describe the Home economy (China), simply noting

[12] This allows us to avoid distinguishing between final- and intermediate-good production functions. As noted by Combes, Mayer, and Thisse (2008), this hypothesis is more realistic than it may at first glance seem. It is well-established that input-output matrices have thick diagonals, meaning that a significant fraction of intermediate goods are used to produce final goods from the same sector.

that similar conditions hold in the Foreign economy. To establish the effects of trade liberalization on the environment relating to the use of (local and imported) intermediates, we first determine the production cost of intermediates and then their demand. The cost of an intermediate variety ω produced at Home is assumed to be:

$$C(m(\omega)) = f + bwm(\omega) = z^{\alpha} M^{\beta} \ell^{1-\beta-\alpha},$$

with $0 < \alpha < 1,\ 0 < \beta < 1, 0 < 1 - \beta - \alpha < 1$, and where w is the manufacturing wage, f is the fixed requirement and b the marginal requirement of labor ℓ, z energy and M intermediates. This latter is assumed to be an aggregate of local and imported intermediates such that

$$M = \left[\int_{\omega \in \Omega_h} m_h(\omega)^{\frac{\sigma-1}{\sigma}} d\omega + \int_{\omega \in \Omega_f} m_f(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}},$$

where $m_j(\omega)$ is the quantity of variety ω produced in country $j = h, f$, used as an intermediate input at home, Ω_j denotes the number of intermediate inputs produced at home h or abroad f, and $\sigma > 1$ is the elasticity of substitution between intermediates. A larger value of the elasticity σ indicates that intermediates can be more easily substituted in the assembly of final goods.

We solve the following minimization problem to determine the cost function for producing a given volume of intermediates $\bar{m}$

$$\underset{M,z,\ell}{\text{minimize}} \qquad (PM + p_z z + w\ell)$$

$$\text{subject to the constraint} \quad bw\bar{m} = z^{\alpha} M^{\beta} \ell^{1-\beta-\alpha} - f,$$

where P is the price index of the aggregate M, and p_z is the price of energy. This program yields the cost function $\bar{C}$ for producing a given variety ω

$$\bar{C} = \left(\frac{1}{\beta\gamma}\right)(bw\bar{m} + f)P^{\beta}p_z^{\alpha}w^{1-\beta-\alpha}, \tag{1}$$

with $\gamma = \left(\frac{\alpha}{\beta}\right)^{\alpha}\left(\frac{1-\beta-\alpha}{\beta}\right)^{1-\beta-\alpha}$.

The use of the duality result of maximizing production subject to the cost constraint yields the simple isoelastic demand for each commodity ω in Home, depending on the source country $j = h, f$ of intermediate production:

$$m_h(\omega) = \left(\frac{p_h(\omega)}{P}\right)^{-\sigma}\frac{E}{P}, \qquad \text{and} \qquad m_f(\omega) = \left(\frac{\tau p_f(\omega)}{P}\right)^{-\sigma}\frac{E}{P}. \tag{2}$$

where E are the expenditures on intermediates in Home, $p_j(\omega)$ the factory gate price of variety ω produced in country $j = f, h$, and τ the trade-cost factor on shipments of intermediate goods from f to h. We assume that $\tau > 1$, as importing intermediate goods from Foreign involves some trade-cost frictions, relating to the movement of the intermediate good to the final user, such as administrative and currency barriers. P is the associated price index of the intermediate goods:

$$P = \left[\int_{\omega\in\Omega_h} p_h(\omega)^{1-\sigma}d\omega + \int_{\omega\in\Omega_f}[\tau p_f(\omega)]^{1-\sigma}d\omega\right]^{\frac{1}{1-\sigma}}. \tag{3}$$

From Home's demand in intermediates (Equation 2) and the cost function (Equation 1), we can answer our central question of whether trade liberalization affects the scale of local polluting production activities. A reduction in trade frictions (lower τ) affects Home's pollution via two channels: a displacement (or composition) effect and a productivity (or scale) effect. We examine each in turn, given that the former is beneficial for the environment, while the latter is detrimental.

The *pollution displacement or composition channel* is straightforward. For the same factory-gate price, the consumption of a foreign intermediate (m_f) is lower by a factor of $\tau^{-\sigma}$ than the consumption of the local intermediate (m_h) (from Equation 2). When Home liberalizes trade, in the sense that trade barriers fall (lower τ), producers consume more of each imported intermediate variety. At the same time, they consume less of each local variety (m_h) as lower τ implies a lower price index P (Equation 3), so that the product market is more competitive. This induces a change in the composition of the total demand for intermediates in Home. Given that the production of intermediates at Home generates pollution as a by-product, the reduction in local demand leads to a variant of what Levinson (2009) calls "pollution displaced by imports". Holding other factors and productivity constant, the more trade is liberalized, the lower is both the demand for local intermediates and pollution.

The *productivity or scale channel* is detrimental for the environment. The cost function of producing local intermediates (Equation 1) depends on the price index P. When Home liberalizes trade, both τ and the price index fall. This leads to a lower production cost for intermediates. In other words, lowering trade costs increases productivity gains. This productivity channel is detrimental to the environment as pollution is a by-product of local intermediates production. This channel is a variant of the well-known scale effect, which arises from the changing scale of the economy.[13]

[13]These two channels (scale and composition) can be complemented by a technique effect if we allow for pollution abatement, as in Antweiler, Copeland, and Taylor (2001).

The main prediction of the model is that the effect of trade liberalization on pollution is unambiguously positive for a given scale of production, but ambiguous otherwise. Empirically, we thus expect processing trade to be more environmentally beneficial than ordinary trade, once we control for the scale of production.

3 Empirical specification

Our empirical analysis assesses the environmental consequences of Chinese cities' trade liberalization. Our empirical specification follows the main literature in this area (Antweiler, Copeland, and Taylor, 2001 and Frankel and Rose, 2005). We investigate the effect of trade intensity on pollution intensity for a given level of income per capita, which commonly captures scale effects (Cole and Elliott, 2003), as required by theory:

$$\ln \text{Pollution}_{ct} = \alpha_c + \alpha_t + \gamma \text{Trade}_{ct} + \beta_1 \ln \text{Income}_{c,t-1} + \beta_2 KE_{ct} + \beta_3 Z_{ct} + \epsilon_{ct}, \qquad (4)$$

where Pollution_{ct} is per-capita sulfur emissions (SO_2) for year t and city c.

We focus on SO_2 emissions as an indicator of pollution for several reasons. First, SO_2 is one of the main air pollutants in China, and is highly correlated with other airborne pollutants.[14] Second, SO_2 is a by-product of goods production, which is consistent with our interest on the effect of trade liberalization on pollution emissions. Third, the impact of SO_2 is more localized compared to other pollutants. It is thus straightforward to link emissions at the city level to local trade performance.

[14] Other major air pollutants in China include particulate matter, ozone and nitrogen dioxide. There are however no statistics on their emissions for a panel of cities over a long period of time.

Fourth, we observe variation in SO_2 across industries and cities. Some industries use more energy and emit more SO_2 than others, so that there is variation in the pollution repercussions of production and trade across cities: cities have different industries and do not produce the same goods. Trade liberalization may thus affect the mix of goods produced across cities over time differently, and hence their emissions. Fifth, we can see the direct implications of trade-related pollution in terms of local health and mortality.[15] Last, changes in SO_2 emissions are less likely to affect GDP growth than are changes in the emissions of other pollutants or other sources of environmental deterioration (such as energy use, deforestation, etc) as argued by Stern and Common (2001). Simultaneity issues should thus be less of a problem with SO_2.[16] While our benchmark specification uses SO_2 emissions per capita, we check the robustness of our results by using SO_2 per GDP and emissions of soot (black carbon).[17]

The trade-openness rate, Trade_{ct}, is measured as the ratio of exports plus imports to GDP. Our main contribution is to uncover the role of international production fragmentation: we will distinguish trade flows according to the ownership type of the firm (foreign or domestic) and the trade regime (ordinary or processing trade). The use of city fixed effects (α_c) controls for any time-invariant city characteristics. Our empirical strategy hence exploits within-city variation over time, and thus addresses the question of the impact of a change in trade openness on city pollution. Moreover, we add year fixed effects α_t that control for annual

[15] Tanaka (2014) finds that efforts to reduce SO_2 emissions in China significantly reduced infant mortality.

[16] By contrast, CO_2 emissions are more endogenous to growth. For instance, deforestation releases large amounts of CO_2 and may also increase income in the short-run by favoring commercial agriculture.

[17] Soot is the main pollutant from burning coal. Poor production methods and widespread use of coal make China the world's largest source of black carbon. This results mainly from coke production, brick making, diesel fuel and household coal. Some of its particles (notably the tiniest ones - qualifying as PM2.5) are the deadliest form of air pollution due to their ability to penetrate unfiltered deep into the lungs and bloodstream, causing permanent DNA mutations, heart attacks, and premature death (World Bank, 2007).

shocks that are common to all Chinese cities.

As argued in the literature, the logarithm of per capita income ($\text{Income}_{c,t-1}$) is used to capture scale, as well as technique, effects. These effects go in opposite directions: while pollution grows with economic activity, the demand for environmental quality and adoption of cleaner production technology are expected to rise with income. A positive association between pollution and income is traditionally interpreted as the domination of the income over the technique effect. We use lagged income to mitigate any simultaneity issues. The city-level capital to employment ratio (KE_{ct}) is introduced to capture local factor endowments.

We adopt an instrumental-variable strategy to address the potential endogeneity of trade openness.[18] We extract exogenous variations in city-level trade openness from two sources: (1) changes in the proximity of foreign suppliers and (2) repercussions from nationally-implemented trade protection of imports and exports. The proximity of foreign suppliers (foreign-supply access) is a trade-cost weighted measure of foreign supplier size, which does not reflect the supply- or demand-side features of Chinese cities. Trade protection relates to average import tariffs and export tax measures, weighted using the product's share in 1997 city imports and exports respectively. These two policy-induced instruments incorporate information on time-varying tax rates that are decided at the national level, hence avoiding any reverse causality from pollution-intensity between 2003 and 2012 at the local level.

Our specification includes a rich set of city controls (Z_{ct}), which account for remaining confounding factors that may be correlated with both city environmental and trade performance. We account for city per capita land area, as population density leads to environmental degradation at a given level of per capita income (Frankel and Rose, 2005). We also control

[18] This is presented in greater detail in Section 4.4.

for three factors that are well-known to be determinants of both technological progress and export performance: foreign-capital intensity, human-capital endowments, and technology development areas (see Wang and Wei (2010)). Foreign capital intensity is proxied by Foreign Direct Investment (FDI) over GDP, reflecting the growing literature suggesting that the large influx of foreign capital into China has resulted in cleaner business practices (Cole, Elliott, and Zhang, 2011; Dean and Lovely, 2010).[19] Second, human-capital endowments are proxied by university-student enrollment. Third, the development of high- and new-tech sectors is picked up by the number of technology development areas.[20] Two additional variables attempt to account for emissions related to the production and consumption structures. The employment share in the secondary sector captures the relative size of manufacturing in the economy, while the annual consumption of electricity (in kwh) accounts for energy demand, which is one of the main sources of emissions.

4 Data, stylized facts and instruments

4.1 Pollution data

Our main variable of interest is the sulfur-dioxide (SO_2) emissions of Chinese cities, which comes from the Urban Statistical Yearbook, published by China's State Statistical Bureau. In robustness checks, we also appeal to soot emissions from the same source.[21] Our final

[19] Looking at the reverse relationship, Lu, Wu, and Yu (2013) show, by way of contrast, that cities with tougher environmental regulations attract less foreign direct investment.

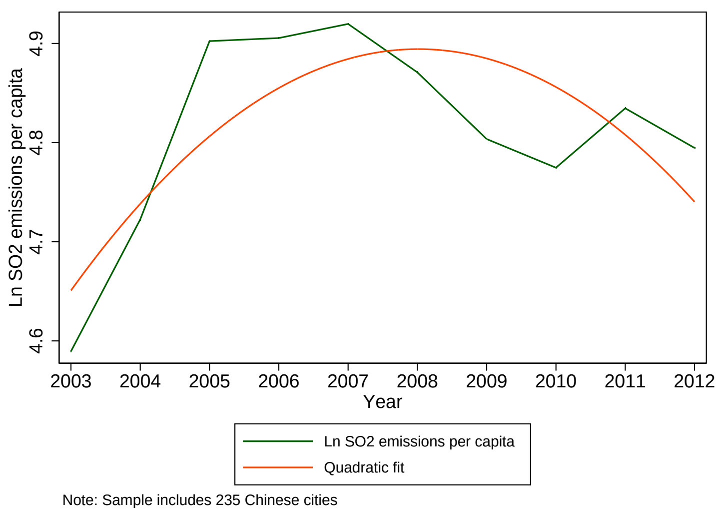
[20] We use the list established by Wang and Wei (2010) of Economic and Technological Development Areas and Hi-Technology Industry Development Areas.

[21] The cross-city correlations between SO_2 and soot are between 0.7 and 0.8 for our sample years.

data set consists of a panel of 235 prefecture-level cities for the years 2003 to 2012.[22]

Figure (1) depicts the evolution of per capita SO_2 emissions between 2003 and 2012. Emission intensity increased until 2007, followed by a downward trend. This hump-shaped curve is consistent with a hypothetical environmental Kuznets curve (EKC), according to which pollution often appears first to worsen and then to improve as country income grows.[23] This stabilization of per capita SO_2 emissions in China is in line with the country's rapid development and the fact that SO_2 is one pollutant for which there is evidence of an EKC (Grossman and Krueger, 1995; Selden and Song, 1994).

Figure 1: Average sulfur-dioxide emissions in China (2003-2012)



[22] 2003 is the first year in which data on SO_2 emissions is available at the city level. We retain cities for which information on income, pollution and trade is not missing, and which are not identified as outliers using the method in Hadi, 1994.

[23] China's GDP per capita has grown at a rate of 10% per year over the last 30 years to attain 4,000 US Dollars in 2010.

4.2 Chinese trade data

We use Chinese customs data from 2003 to 2012. Export and import flows are aggregated at the 4-digit (city) location-level.[24] We can distinguish trade flows according to the ownership type of the firm (foreign or domestic) and trade regime (ordinary or processing trade).[25]

4.3 City-level macro indicators

Macroeconomic indicators at the city-level such as GDP, population, electricity consumption, employment share in manufacturing, FDI, university student enrollment and land area, which are used as controls in the regressions, come from China Data Online, provided by the University of Michigan. The capital abundance of cities K corresponds to the physical capital stock, calculated according to the method used by Mankiw, Romer, and Weil (1992) and described in the Appendix.

4.4 Instruments

We address the endogeneity of trade with respect to pollution by focusing on that part of city trade performance that is driven by proximity to foreign suppliers and China's trade protection. We hence instrument Chinese cities' trade openness using their foreign supply access and average import tariff and export tax.

[24] China is divided into four municipalities (Beijing, Tianjin, Shanghai and Chongqing) and 27 provinces which are further divided into prefectures. As is common in the literature, we use the terms city and prefecture interchangeably, even though prefectures include both an urban and a rural part.

[25] The data collected by Chinese Customs include annual export values by city at the HS 8-digit product level. This product dimension is used to calculate the two instruments based on import and export tariffs. To account for the changes in the HS classification in 2002, 2007 and 2012, we aggregate the data to the HS 6-digit level (1996 revision). The correspondence tables from UNCTAD can be found at http://unstats.un.org/unsd/trade/conversions/HS Correlation and Conversion tables.htm.

Foreign supply access

Foreign supply access is calculated using international trade data.[26] This measures proximity to foreign suppliers and does not reflect Chinese cities' local demand and supply factors that could also lead to greater trade flows but are potentially endogenous to local SO_2 emissions. The main idea underlying this indicator is that a location's import performance depends on its accessibility to potential trading partners. Locations closer to large supplier markets have greater supply access due to lower trade costs. This gives them a competitive advantage in importing from these markets, and we thus expect locations with greater supply access to import more. The estimation of supply access follows the methodology proposed by Redding and Venables (2004). We estimate a standard trade equation on bilateral trade flows separately for each year of our sample. All of the estimated coefficients can then vary over time, which enables us to construct yearly city-level foreign supply access measures. The supply performance of Chinese cities' international partners is constructed using the annual estimates of the following standard trade equation:

$$\ln EX_{ij} = \underbrace{\delta \ln d_{ij} + \eta B_{ij} + \vartheta WTO_{ij}}_{\text{Bilateral trade costs}} + FX_i + FM_j + \epsilon_{ij}, \tag{5}$$

where EX_{ij} denotes bilateral exports, between trading partners i and j,[27] explained by bilateral trade costs as well as exporter and importer dummies. Trade costs between i and j can be specified using different variables. We consider bilateral distance (d_{ij}), whether partners share a common border (B_{ij}), and whether the two are members of the WTO or its predecessor GATT (WTO_{ij}). These variables are obtained from CEPII. Distance between

[26] International trade data for 179 countries is obtained from the IMF Direction of Trade Statistics (DOTS).
[27] Trading partners include Chinese cities and 179 foreign countries.

Chinese cities and foreign countries is constructed using latitudes and longitudes for each trading partner and the 17 largest Chinese harbors. Since most of China's trade is shipped by boat, we first calculate the geodesic distance of each Chinese city to the closest harbor and then add the geodesic distance from the harbor to the final (foreign) destination.[28]

Equation 5 provides us with yearly estimates of the two components of supply access: freeness of trade and supply capacity. Importer fixed effects correspond to the log of the unobserved market capacity of the importing region j, while exporter fixed effects (FX_i) capture the log of the exporter's supply capacity. The latter picks up whatever makes exporter i competitive, including the number of firms, their total output and their price competitiveness. The importer fixed effect (FM_j) captures all the considerations that make destination j attractive.[29] The higher is FX_i, the greater its supply capacity and thus the more it exports to each destination partner.

Based on the annual estimates of the covariates and fixed effects in Equation 5, we construct each city's foreign supply access (FSA_{ct}) by summing the partners' predicted supply capacity, FX_i, weighted by the estimates of the corresponding bilateral trade costs:

$$\text{FSA}_{ct} = \textstyle\sum_{i \in R} \exp(\widehat{\delta}_t \ln d_{ic} + \widehat{\eta}_t B_{ic} + \widehat{\vartheta}_t WTO_{ict} + \widehat{FX_{it}}). \tag{6}$$

where R denotes the set of foreign countries. Foreign supply access hence corresponds to a trade-cost weighted measure of suppliers' size. It does not capture Chinese cities' supply-side

[28]The ports used are Beibuwan, Dalian, Fuzhou, Guangzhou, Lianyungang, Qingdao, Qinhuangdao, Rizhao, Shanghai, Shenzhen, Suzhou, Tangshan, Tianjin, Xiamen, Yingkou, Zhanjiang and Zhoushan.

[29]It thus reflects the market capacity of importer j, which depends on its total expenditure on imported goods and the prevailing price index. The higher is FM_j, the greater its market capacity and thus the greater its demand for imported goods from each country of origin.

features such as local comparative advantage due to the availability of specific resources, any particular production technology or greater local productivity. It also does not incorporate local demand-side features such as income per capita.

Trade protection

Our two instruments refer to average tariffs, based on import and export data. We calculate the weighted average of product-level nominal tariff protection applied to imports into China, using the product's share in 1997 city imports as the weight. Annual data on MFN tariffs at the HS6-level come from the World Integrated Trade Solution (WITS).

Export taxation is common in China. A growing literature on the Chinese VAT system (Chandra and Long, 2012; Evenett, Fritz, and Jing, 2012; Gourdon, Hering, Monjon, and Poncet, 2014) highlights that an ad-valorem tax on exports is imposed when goods receive a VAT refund rate that is lower than the applicable VAT rate. Over the 2002-2012 period, only 13% of the products in China received rebates compensating for VAT. Incomplete rebates, which are equivalent to export taxation (Feldstein and Krugman, 1990), are hence the rule in China. Our measure of export tax is the share of non-refunded VAT [=(1-VAT rebate)/VAT rate]. VAT rebate rates and VAT rates at the tariff-line level (HS 8-digit or more disaggregated levels) are taken from the Etax yearbooks of Chinese Customs.[30] We calculate the weighted average of the product-level share of non-refunded VAT, using the product's share in 1997 city exports as the weight.

To further ensure the reliability of our IV strategy, both taxation-related instruments are

[30] To account for the changes in the HS classification in 2002, 2007 and 2012, we aggregate the data to the HS 6-digit level (1996 revision) using the yearly average of these rates. We use the simple average of all tariff lines within a HS6 product and all sub-periods within the year.

lagged one year with respect to the trade-openness indicator.

5 Results

5.1 Benchmark results

Table 1 shows the estimates for Equation 4, instrumenting trade openness with the three instruments described above. Columns 2 to 4 progressively add additional controls to our benchmark specification in column 1. The estimated effect of trade openness on SO_2 per capita emissions is always negative and significant, suggesting that greater trade openness has a beneficial effect on the environment.

We check that our instruments are not weak and are valid. The first stage of the estimations in Table 1 appears in Appendix Table A-3. These first-stage results suggest that greater proximity to foreign suppliers boosts the trade performance of Chinese cities, while a rise in the weighted average tariffs on exports and imports reduces trade openness (although the estimated coefficient on the import tax is insignificant). The partial explanatory power of the three instruments is roughly 2.2% and the F-test of their joint insignificance is rejected at the 1% level. The OLS results, corresponding to the IV results of Table 1, appear in Table A-2 and show an insignificant effect of trade openness on pollution. The OLS results then seem to be upward-biased. This either reflects measurement error, which typically induces a bias toward zero, or the omission of variables that are correlated with both trade openness and emissions, such as the availability of natural resources or large and competitive supply capacity. Additional test statistics regarding our instruments appear at the foot of Table 1. These show that our instruments pass standard validity assessments.[31] The Angrist-Pischke first-stage Chi-squared statistics reject the null of under-identification (Angrist and Pischke, 2009). This indicates that we do not suffer from weak instruments. The Hansen test of overidentifying restrictions for the excluded instruments is not rejected and hence does not exclude the exogeneity of our instruments.

The trade-openness estimate is virtually unchanged in column 2 when adding controls for city per capita land area, inflows of foreign investment, university-student enrollment and a dummy denoting the presence of a technology development area. Column 3 further adds the employment share in the secondary sector and total electricity consumption to account for emission sources related to production and consumption structures. This specification constitutes our benchmark in the remaining tables. All these control variables attract coefficients with the expected signs. The proxies for education and technology-promoting policy enter with significant negative signs, confirming that pollution is lower in locations with greater levels of skill and technology. Moreover, the estimates are negative for FDI, education and technology-supporting policy, and positive for the employment share in manufacturing and electricity consumption. These are all significant at the 1% confidence level, except for FDI.

The empirical specification in column 4 follows the theoretical work of Antweiler, Copeland, and Taylor (2001),[32] where the squares of per capita income and capital endowment are intro-

[31] The first stage F-statistics on the excluded instruments match the informal threshold of 10 suggested by Staiger and Stock (1997) to assess instrument validity.

[32] In their model, emissions come from three main sources: scale, composition and technique effects. The scale effect represents the change in emissions from a change in the size of the economy, all else equal. The composition effect reflects the change in emissions due to a change in the mix of goods produced, e.g. devoting more resources to producing a polluting good will pollute more. These two effects mirror the productivity and displacement effects highlighted in our theory. The technique effect corresponds to a change in the pollution intensity of the dirty industry. As mentioned, this latter effect can be added to the model if we allow for pollution abatement.

Table 1: The impact of trade openness on SO_2 emissions

Dependent variable	Ln SO2 emissions per capita			
	(1)	(2)	(3)	(4)
Trade openness ([X+M]/GDP)	-0.068^a	-0.067^a	-0.073^a	-0.078^a
	(0.017)	(0.016)	(0.018)	(0.019)
Lagged ln GDP per capita	-0.205	-0.174	-0.238	0.443
	(0.155)	(0.152)	(0.164)	(1.372)
Capital Abundance (K/E)	-0.224	-0.040	0.175	15.703
	(0.892)	(0.893)	(0.951)	(17.961)
ln Land area per capita		-0.001	0.001	0.001
		(0.003)	(0.003)	(0.003)
FDI over GDP		-0.013	0.012	-0.020
		(0.096)	(0.101)	(0.106)
Share of Univ. students over population		-1.355^a	-1.324^a	-0.968^b
		(0.380)	(0.392)	(0.403)
Technology development area		-0.344^c	-0.510^b	-0.599^b
		(0.208)	(0.239)	(0.254)
Employment share in secondary sector			1.444^a	1.520^a
			(0.513)	(0.558)
ln Electricity consumption			0.203^a	0.194^a
			(0.055)	(0.055)
Lagged $[\ln(\text{GDP per capita})]^2$				-0.027
				(0.076)
$(K/E)^2$				21.878^c
				(12.922)
K/E × Lagged ln GDP per capita				-1.959
				(1.950)
City and year fixed effects	Yes	Yes	Yes	Yes
No. of observations	2,289	2,289	2,289	2,289
No. of cities	235	235	235	235
Partial R^2 of excluded instruments	0.021	0.022	0.021	0.019
Underidentification test	29.36	29.20	27.78	22.75
Weak identification test	14.12	14.22	14.06	11.43
Hansen (p-value)	0.20	0.24	0.35	0.48

Heteroskedasticity-robust standard errors appear in parentheses. ^{a}, ^{b} and ^{c} indicate significance at the 1%, 5% and 10% confidence levels. The underidentification test is based on the Kleibergen-Paap rk LM-statistic, with ^{a} indicating that the p-value (Chi-sq(2)) is below 0.01, suggesting that underidentification is rejected. The weak identification test is based on the Kleibergen-Paap Wald rk F-statistic. The F-statistic is above 10, the informal threshold suggested by Staiger and Stock (1997) to assess instrument validity. The Hansen J-statistic is an overidentification test of all instruments. The Chi-sq(2) p-value above 0.10 suggests that the model is overidentified and the instruments are exogenous.

duced to allow for non-linear effects. The environmental Kuznets curve literature does indeed propose a hump-shaped relationship between per capita income and pollution (Grossman and Krueger, 1993; Selden and Song, 1994). Moreover, the interaction $KE \times \ln \text{Income}_{c,t-1}$ captures any effect of per capita income on pollution that depends on relative capital endowments, and vice versa. All the three additional controls enter positively, although only the estimated coefficient on $(\text{K/E})^2$ is significant at the 10% level.

The coefficients on trade openness are relatively similar in Table 2, which adopts alternative measures of openness (columns 1 and 2) and pollution (columns 3 and 4). In the first two columns trade openness is calculated using domestic value-added (DVA) in trade instead of the value of trade. This allows us to check that our results do not simply reflect any overstatement of Chinese trade openness related to the well-known "double-counting" problem when processing trade is pervasive (Johnson and Noguera, 2012; Koopman, Wang, and Wei, 2012). Our city-level trade openness ratios are distorted measures of local internationalization due to the high share of imported intermediates. In column 1, we compute the city-level DVA in trade using the sector-level ratios of DVA from Koopman, Wang, and Wei (2012) for 2002 to extract the DVA incorporated in trade flows for each city-sector-year triplet, which we then sum to the city-year level.[33] Column 2 takes an alternative approach based on firm-level data. We use firm-level declarations of imports and exports in 2006[34] and approximate the DVA content in exports for a firm-HS4 digit product pair as the firm export value net of the import value for that HS4 product. We thus remove the intra-firm re-exported imports within a given HS4 product prior to calculating its total trade. After

[33] We use the concordance table between sectors and HS6 products from Upward, Wang, and Zheng (2013).
[34] This is the latest year for which we have the firm-level customs data.

Table 2: The impact of trade openness on SO_2 emissions: alternative measures

Dependent variable	Ln SO2 emissions per capita		over GDP	Ln Soot emissions per capita
	(1)	(2)	(3)	(4)
Domestic VA of Trade openness (method 1)	-0.108[a]			
	(0.027)			
Domestic VA of Trade openness (method 2)		-0.100[a]		
		(0.022)		
Trade openness ([X+M]/GDP)			-0.077[a]	-0.090[a]
			(0.018)	(0.022)
Lagged ln GDP per capita	-0.295[c]	-0.363[b]	-1.022[a]	-0.379[c]
	(0.174)	(0.151)	(0.174)	(0.223)
Capital Abundance (K/E)	-0.085	-0.117	0.189	2.319[c]
	(0.977)	(0.759)	(0.975)	(1.277)
ln Land area per capita	0.001	0.001	0.001	0.009[b]
	(0.003)	(0.003)	(0.003)	(0.004)
FDI over GDP	0.034	0.034	0.002	-0.231[c]
	(0.097)	(0.086)	(0.105)	(0.132)
Share of Univ. students over population	-1.037[a]	-1.431[a]	-1.431[a]	-1.658[a]
	(0.338)	(0.382)	(0.404)	(0.519)
Technology development area	-0.422[b]	-0.375[c]	-0.627[b]	-0.720[c]
	(0.215)	(0.204)	(0.251)	(0.418)
Employment share in secondary sector	1.091[b]	1.176[a]	1.485[a]	1.973[a]
	(0.452)	(0.404)	(0.526)	(0.672)
ln Electricity consumption	0.175[a]	0.193[a]	0.205[a]	0.168[b]
	(0.051)	(0.050)	(0.056)	(0.066)
City and year fixed effects	Yes	Yes	Yes	Yes
No. of observations	2,289	2,289	2,289	2,289
No. of cities	235	235	235	235
Partial R^2 of excluded instruments	0.021	0.036	0.021	0.021
Underidentification test	27.53	37.62	27.78	27.78
Weak identification test	12.36	19.86	14.06	14.06
Hansen (p-value)	0.24	0.13	0.23	0.59

Heteroskedasticity-robust standard errors appear in parentheses. [a], [b] and [c] indicate significance at the 1%, 5% and 10% confidence levels. The underidentification test is based on the Kleibergen-Paap rk LM-statistic, with [a] indicating that the p-value (Chi-sq(2)) is below 0.01, suggesting that underidentification is rejected. The weak identification test is based on the Kleibergen-Paap Wald rk F-statistic. The F-statistic is above 10, the informal threshold suggested by Staiger and Stock (1997) to assess instrument validity. The Hansen J-statistic is an overidentification test of all instruments. The Chi-sq(2) p-value above 0.10 suggests that the model is overidentified and the instruments are exogenous. Domestic value-added in trade (method 1) is calculated using sector-level ratios of domestic value-added from Koopman, Wang, and Wei (2012) for 2002. Domestic value-added in trade (method 2) is calculated using the HS4-level ratios of domestic value-added calculated from firm-level data for 2006.

summing over firms for a given HS4 product, we calculate the share of domestic value-added content in trade for that HS4 product as the ratio of (net exports plus imports) over exports plus imports. Whatever the approach used to address the "double-counting" problem, the negative association between trade openness and emissions remains when the former is measured in terms of the value-added content of trade. The point estimate is slightly higher, but not statistically different from that in our benchmark.

Column 3 measures pollution intensity dividing SO_2 emissions by GDP, and column 4 considers soot emissions per capita. Our finding of a negative and significant effect of trade on emissions continues to hold for these alternative emissions measures, so that our results do not depend on scaling or the pollution measure.

Our point estimate is robust across specifications and suggests that a 1 percentage point increase in trade openness reduces emission intensity by about 7%. Over our sample period (2003-2012) the average annual change in city-level trade openness was 2.2 percent, so that emission intensity fell by 15% annually as a result of China's greater outward orientation. This value does however mask enormous spatial heterogeneity. Comparing the 75^{th} and 25^{th} percentile cities in terms of the annual change in trade openness (-4.8 and + 5.3 percentage points, respectively) the point estimate implies that pollution emissions per capita rose by 33% per annum for the former but fell by 36% p.a. for the latter.

Table 3 carries out additional robustness tests. We first check that our results hold after excluding some particular geographic zones. As emphasized in the literature on Chinese export performance (Amiti and Freund, 2010; Wang and Wei, 2010), a number of Chinese localities are clearly different from the others in terms of location and policy particularities, which have made them richer, faster-growing, more open, and more likely to host firms with rapid export growth. Column 1 excludes cities in the Western provinces to check that the results are not driven by observations from these landlocked and mountainous areas, which are mostly populated by ethnic minorities.[35] The literature on China has underlined an interior-coast divide. Interior locations are considered to be significantly different from the rest of the country; their economies are more inward-oriented and have had limited success in attracting foreign investment. In column 2, we restrict our sample to coastal locations, which account for around 90% of the country's trade. Despite the smaller number of observations, the coefficient on trade remains negative and significant, so the pollution repercussions of trade are also found in these areas that are responsible for the bulk of trade and growth in China.[36]

The last three columns of Table 3 exclude cities according to different criteria to determine whether extreme values are behind our results. In column 3, the criterion is SO_2 emissions per capita in 2003 (excluding the top and bottom 2% of cities by pollution intensity). In column 4, the criterion is the growth in trade openness between 2003 and 2012 (excluding the top and bottom 2% internationalizing cities). In column 5, the criterion is the growth in per capita GDP between 2003 and 2012 (excluding observations in the top and bottom 2%). Our trade-openness variable remains negative and significant throughout, suggesting that the negative association between trade openness and pollution intensity is robust. In unreported tables available upon request, we find qualitatively similar results when replicating Table 3 using domestic value-added (DVA) in trade instead of the value of trade and using soot emissions per capita to measure pollution.

[35] The Western part of China includes Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang provinces.

[36] In unreported results (available upon request), we also check that our results continue to hold when the regressions are re-estimated excluding one province at a time.

Table 3: Robustness checks: The impact of trade openness on SO_2 emissions

Dependent variable	Ln SO2 emissions per capita				
Sample restriction	No western locations	Only coastal locations	w/o locations in top & bottom 2% in terms of SO_2 per capita	Trade-openness growth	Income per capita growth
	(1)	(2)	(3)	(4)	(5)
Trade openness ([X+M]/GDP)	-0.084[a]	-0.098[a]	-0.052[a]	-0.071[a]	-0.059[a]
	(0.019)	(0.025)	(0.015)	(0.017)	(0.018)
Lagged ln GDP per capita	-0.167	-0.683[c]	-0.104	-0.169	0.004
	(0.194)	(0.387)	(0.120)	(0.156)	(0.151)
Capital Abundance (K/E)	0.905	5.505[b]	-0.161	0.460	-0.575
	(1.144)	(2.531)	(0.756)	(0.884)	(0.864)
ln Land area per capita	0.006[b]	0.032	0.001	0.003	0.002
	(0.003)	(0.055)	(0.003)	(0.004)	(0.003)
FDI over GDP	-0.038	-0.105	0.010	-0.111	0.006
	(0.123)	(0.164)	(0.080)	(0.090)	(0.087)
Share of Univ. students over population	-2.063[a]	-2.915[a]	-0.924[a]	-1.538[a]	-1.220[a]
	(0.510)	(0.902)	(0.315)	(0.409)	(0.382)
Employment share in secondary sector	1.709[a]	4.992[a]	0.975[b]	1.176[b]	1.137[b]
	(0.657)	(1.542)	(0.415)	(0.471)	(0.490)
ln Electricity consumption	0.262[a]	0.434[b]	0.169[a]	0.296[a]	0.190[a]
	(0.082)	(0.171)	(0.048)	(0.066)	(0.055)
Technology development area			-0.285	-0.514[b]	-0.399[c]
			(0.187)	(0.239)	(0.240)
City and year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	1870	905	2194	2169	2163
No. of cities	191	93	224	221	221
Partial R^2 of excluded instruments	0.023	0.022	0.021	0.024	0.017
Underidentification test	25.37	18.64	26.54	29.70	20.51
Weak identification test	13.88	8.78	13.46	15.66	10.47
Hansen (p-value)	0.67	0.25	0.62	0.27	0.42

Heteroskedasticity-robust standard errors appear in parentheses. [a], [b] and [c] indicate significance at the 1%, 5% and 10% confidence levels. The underidentification test is based on the Kleibergen-Paap rk LM-statistic, with [a] indicating that the p-value (Chi-sq(2)) is below 0.01, suggesting that underidentification is rejected. The weak identification test is based on the Kleibergen-Paap Wald rk F-statistic. The F-statistic is above 10, the informal threshold suggested by Staiger and Stock (1997) to assess instrument validity. The Hansen J-statistic is an overidentification test of all instruments. The Chi-sq(2) p-value above 0.10 suggests that the model is overidentified and the instruments are exogenous.

5.2 The role of the international segmentation of production

In this section, we explore the potential role of international production fragmentation as the main driver of the negative effect of trade on local pollution intensity. The structure and composition of Chinese trade flows depend greatly on firm ownership and the type of trade. We may thus expect that the repercussions of trade on the environment also vary according to these criteria. Trade growth affects pollution through a number of channels with potentially contrasting effects (Antweiler, Copeland, and Taylor, 2001; McAusland and Millimet, 2013). The overall impact will notably depend on the relative strength of the composition[37] and technological effects.[38] Moreover, our model developed in Section 2 stresses two specific channels (displacement/composition and productivity/scale) via which the use of imported intermediate inputs affects pollution emissions, further suggesting an environmental effect of trade openness that differs by trade regime.

The literature suggests environmentally-positive composition effects from processing trade. Dean and Lovely (2010) calculate the pollution intensity of Chinese exports and imports from 1995-2004 at the national level,[39] and find that pollution-intensive sectors account for a shrinking part of the processing-export bundle. They also find a negative association between pollution intensity and both FDI and the share of processing activities in trade, indicating that both processing trade and foreign firms have contributed to reducing the pollution intensity of Chinese trade.

[37]Emissions may rise if the composition of output is biased towards dirty goods or if the emergence of new goods induces a substitution effect away from other goods, including environmental quality.

[38]Emission intensity may fall if trade expansion induces technical change that prompts the use of cleaner production techniques or if it raises income and residents demand more of all goods, including a cleaner environment, as they become wealthier.

[39]They consider four pollutants: chemical oxygen demand, SO_2, smoke and dust.

The theoretical arguments do not then all point in the same direction but, controlling for the scale of production, the effect of trade openness on pollution is unambiguously more positive for processing activities than for ordinary activities. The literature notably has documented the persistent greater efficiency of foreign firms compared to domestic firms in China (Blonigen and Ma, 2010), suggesting that trade fragmentation and FDI may render China's trade environmentally beneficial.

Table 4 shows the estimates for Equation 4, distinguishing trade openness in turn by firm ownership in columns 1 and 2 and trade regime in columns 3 and 4. To maximize the explanatory power of the first-stage equation and avoid issues relating to weak instruments, our instruments should explain the two dimensions of trade openness (exports and imports) as well as the two regimes (ordinary and processing). The best fit results from the use of four instruments that build on those used in our aggregate trade results: supply access, the interaction of supply access with a coast dummy, the weighted export tax and the interaction of the weighted import tax and the coast dummy. The rationale for the interaction of the instruments with the coast dummy is not to impose the same relationship between trade openness and its exogenous determinants across the Chinese coast-interior divide.

The various tests of instrument weakness appear at the foot of Table 4. The overidentification Hansen J-statistic is also shown, which evaluates instrument exogeneity. None of these tests reject instrument validity. The first stage of the estimations in Table 4 appear in Table A-4 in the Appendix. First-stage results suggest that greater proximity to foreign suppliers increases the trade performance of domestic firms across China, and benefits that of foreign firms mostly on the coast. An increase in the weighted average tax on exports is mostly detrimental to processing/foreign trade, while higher import duties benefit ordinary trade. Both of these results are consistent with expectations. First, firms in ordinary trade can strategically respond to higher export taxes by reorienting their sales domestically, whereas processing firms cannot, as assembled goods are to be re-exported and cannot be sold domestically (Brandt and Morrow, 2013. Second, firms in ordinary trade pay duties on their imports while processing trade firms do not.

Column 1 of Table 4 distinguishes between foreign-owned and domestic firms. There is a negative and significant effect of trade on SO_2 pollution for both firm-ownership types, with that for domestic trade being much smaller than that in our benchmark specification. The coefficient on trade openness for foreign firms is one-third the size of that for domestic firms (-0.09 versus -0.03). When we add more controls in column 2, this hierarchy continues to hold, with the repercussions of domestic-firm trade becoming insignificant. To see whether this differential effect reflects trade regimes, as foreign firms are mostly active in processing trade, we split trade flows according to trade type in columns 3 and 4.

Given the strong correlation between processing trade and foreign-firm trade, it is unsurprising that the two attract similar coefficients. The strong, negative and significant effect of trade on pollution comes mostly from processing trade, with an estimated coefficient that is over twice as large as our benchmark estimate (column 3 of Table 1). This difference continues to hold after the inclusion of controls for population density, FDI, education, technology development zones, the employment share in manufacturing and electricity consumption in column 4. The results again appear to be robust. This suggests that our IV approach has been successful in identifying an exogenous source of trade openness that is independent of FDI and other traditionally-proposed proxies of technological progress, which are often thought to be correlated with environmental or trade performance.

Table 4: The heterogenous effect of trade openness on SO_2 emissions by type of trade

Dependent variable	Ln SO2 emissions per capita			
	(1)	(2)	(3)	(4)
Trade openness (domestic firms)	-0.031^c	-0.037^b		
	(0.018)	(0.019)		
Trade openness (foreign firms)	-0.091^a	-0.088^a		
	(0.025)	(0.024)		
Trade openness (ordinary trade)			-0.023	-0.030
			(0.019)	(0.020)
Trade openness (processing trade)			-0.107^a	-0.104^a
			(0.029)	(0.028)
Lagged ln GDP per capita	0.029	-0.037	-0.038	-0.094
	(0.167)	(0.170)	(0.147)	(0.145)
Capital Abundance (K/E)	-0.571	-0.201	-0.829	-0.539
	(0.937)	(0.949)	(0.835)	(0.876)
ln Land area per capita		-0.001		-0.001
		(0.003)		(0.003)
FDI over GDP		0.053		0.028
		(0.107)		(0.105)
Share of Univ. students over population		-0.988^a		-0.848^b
		(0.367)		(0.380)
Technology development area		-0.132		-0.682^b
		(0.214)		(0.289)
Employment share in secondary sector		1.294^a		1.167^a
		(0.468)		(0.431)
ln Electricity consumption		0.173^a		0.185^a
		(0.049)		(0.051)
City and year fixed effects	Yes	Yes	Yes	Yes
Observations	2,289	2,289	2,289	2,289
No. of cities	235	235	235	235
Partial R^2 of excluded instruments	0.026	0.027	0.028	0.028
Underidentification test	27.24	27.84	32.99	31.88
Weak identification test	10.20	10.51	10.17	9.50
Hansen (p-value)	0.21	0.17	0.73	0.61

Heteroskedasticity-robust standard errors appear in parentheses. ^{a}, ^{b} and ^{c} indicate significance at the 1%, 5% and 10% confidence levels. The underidentification test is based on the Kleibergen-Paap rk LM-statistic, with ^{a} indicating that the p-value (Chi-sq(2)) is below 0.01, suggesting that underidentification is rejected. The weak identification test is based on the Kleibergen-Paap Wald rk F-statistic. The critical value of the Staiger and Stock (2005) F-statistic to assess instrument validity for two endogenous regressors and four instruments is 7.56 for 10% maximal IV relative bias. The Hansen J-statistic is an overidentification test of all instruments. A Chi-sq(2) p-value above 0.10 suggests that the model is overidentified and the instruments are exogenous.

Our results thus underline a negative significant effect of trade on emissions that mostly relates to processing trade and the activities of foreign firms: the environmental gains from ordinary trade activities and domestic firms are much lower.[40]

There are a number of potential factors behind these findings. First, as we expected theoretically, conditional on scale effects, trade liberalization produces a displacement/composition effect, which is beneficial for the environment. Ordinary trade appears to be relatively more skewed towards capital and energy-intensive industries, which have higher emission intensities. The main product exported under the ordinary regime is textiles, accounting for a quarter of the exported value in 2012, while processing exports consist mainly of electronics (accounting for 50% of the value in 2012). Dean and Lovely (2010) find that SO_2 emissions (in kilos per thousand Yuan of output) are 20 times higher in textiles than in electronics. In addition, China's trade has shifted toward cleaner sectors over time, and in particular in processing trade, leading Dean and Lovely (2010) to conclude that processing trade has made China's trade cleaner. Finally, processing trade is much more technologically advanced than ordinary trade: high-technology products (according to to the technology classification in Lall (2000)) accounted for 21% of processing exports in 2012, which is twice the figure for domestic exports.

An additional particularity of processing trade is its geographical orientation. Close to 92% of processing trade is directed to or emanates from developed countries in the period under consideration, compared to 77% for ordinary trade.[41] Sharper environmental concerns and stricter pollution regulations in developed countries may lead to less harmful environ-

[40]In unreported results that are available upon request we find similar results for soot emissions.

[41]Developed countries are identified as those with a GNP per capita over 10,000 US Dollars (obtained from the World Bank indicators).

mental practices for processing activities. In unreported results (available upon request) we investigate this channel by separating developed and developing partner countries. The relationship between trade openness and SO_2 emissions per capita is negative and significant for trade with developed countries while no such pattern pertains for trade with developing countries. The consistent message in our results is then that the environmental benefits from increased trade orientation identified in Section 5.1 mostly come from processing trade. The "pro-environmental" effect of processing trade suggests that the ongoing rebalancing process in which China is trying to increase the contribution of domestic consumption and reduce its reliance on processing activities may be detrimental for the environment.

Table 5 checks that our results, and notably the different environmental repercussions of trade openness by firm ownership or trade regime, do not simply come from processing (foreign-dominated) exports being a less good measure of a location's internationalization, due to the high share of imported intermediates.

We recalculate the various trade-openness measures using the domestic value-added content of imports and exports instead of the total value of trade.[42] Measuring trade openness only via the domestic value-added (DVA) content ensures that increasing trade openness reflects higher production. Columns 1 and 2 of Table 5 examine the separate effect of trade openness for foreign and domestic firms while columns 3 and 4 differentiate between processing and ordinary trade. Our results continue to hold when using DVA: there is a negative and significant effect of trade on emissions. This effect is larger for processing trade and activities undertaken by foreign firms: the environmental gains from either ordinary trade

[42] The domestic value-added in trade is computed using HS4-level ratios of domestic value-added calculated from firm-level data for 2006 (method 2); similar results are obtained using the sector-level ratios from Koopman, Wang, and Wei (2012).

Table 5: Heterogenous effects by type of trade: domestic value-added (DVA) content

Dependent variable	Ln SO2 emissions per capita			
	(1)	(2)	(3)	(4)
Domestic VA Trade openness (domestic firms)	-0.039^c	-0.044^b		
	(0.020)	(0.021)		
Domestic VA Trade openness (foreign firms)	-0.345^a	-0.338^a		
	(0.091)	(0.089)		
Domestic VA Trade openness (ordinary trade)			-0.036^c	-0.042^b
			(0.020)	(0.021)
Domestic VA Trade openness (processing trade)			-0.379^a	-0.371^a
			(0.098)	(0.096)
Lagged ln GDP per capita	0.062	0.008	-0.066	-0.121
	(0.169)	(0.175)	(0.133)	(0.134)
Capital Abundance (K/E)	-0.432	-0.120	-0.704	-0.400
	(1.082)	(1.113)	(0.843)	(0.895)
ln Land area per capita		0.000		-0.001
		(0.003)		(0.003)
FDI over GDP		0.092		0.021
		(0.117)		(0.098)
Share of Univ. students over population		-0.880^b		-0.820^b
		(0.366)		(0.350)
Technology development area		-0.229		-0.159
		(0.226)		(0.142)
Employment share in secondary sector		1.295^a		1.008^b
		(0.489)		(0.400)
ln Electricity consumption		0.156^a		0.170^a
		(0.046)		(0.047)
City and year fixed effects	Yes	Yes	Yes	Yes
Observations	2,289	2,289	2,289	2,289
No. of cities	235	235	235	235
Partial R^2 of excluded instruments	0.027	0.027	0.043	0.042
Underidentification test	26.60	26.44	41.42	38.38
Weak identification test	9.73	9.53	11.71	10.71
Hansen (p-value)	0.20	0.15	0.60	0.50

Heteroskedasticity-robust standard errors appear in parentheses. ^{a}, ^{b} and ^{c} indicate significance at the 1%, 5% and 10% confidence levels. The underidentification test is based on the Kleibergen-Paap rk LM-statistic, with ^{a} indicating that the p-value (Chi-sq(2)) is below 0.01, suggesting that underidentification is rejected. The weak identification test is based on the Kleibergen-Paap Wald rk F-statistic. The critical value of the Staiger and Stock (2005) F-statistic to assess instrument validity for two endogenous regressors and four instruments is 7.56 for 10% maximal IV relative bias. The Hansen J-statistic is an overidentification test of all instruments. A Chi-sq(2) p-value over 0.10 suggests that the model is overidentified and the instruments are exogenous. The domestic value-added in trade is calculated using HS4-level ratios of domestic value-added calculated from firm-level data for 2006.

activities or domestic firms are much smaller, even though these are currently the main drivers of China's export and import growth.

Table 6 proposes a number of sample checks as Table 3, to ensure that our results do not depend on particular locations or outliers.

The odd columns distinguish between domestic and foreign trade openness, while even columns differentiate between ordinary and processing trade. The significant negative effect of trade openness on pollution emissions, which is larger for processing and foreign-handled trade, remains. The results consistently indicate that trade's environmental benefits are mostly found in processing trade, which is largely handled by foreign firms.[43]

6 Conclusion

We use recent detailed panel data on trade and pollution emissions covering 235 Chinese cities to assess the environmental consequences of China's integration into the world economy. We explore the differential effects of processing versus ordinary trade, and address the potential endogeneity of trade and pollution via the inclusion of various fixed effects and instrumental variables. We find a negative and significant effect of trade on emissions that is larger for processing trade and activities undertaken by foreign firms: the environmental gains from either ordinary trade activities or domestic firms are much lower, even though these are currently the main drivers of China's export and import growth. This result suggests some caution regarding the future pollution prospects in the context of China's ongoing transition

[43] In unreported results, which are available upon request, we check that all our results hold when we further control for the share of polluting sectors in imports and exports separately. Polluting sectors (at the 2-digit ISIC level) are defined as those for which the ratio of SO_2 emissions over output is above the median across sectors.

Table 6: Heterogenous effects by type of trade: Sample checks

Dependent variable	Ln SO2 emissions per capita							
Sample restriction	No Western locations		w/o locations in top & bottom 2% in terms of SO$_2$ per capita		Trade openness growth		Income per capita growth	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Trade openness (domestic firms)	-0.059[b]		-0.032[b]		-0.033[c]		-0.027	
	(0.023)		(0.015)		(0.020)		(0.017)	
Trade openness (foreign firms)	-0.091[a]		-0.062[a]		-0.090[a]		-0.074[a]	
	(0.024)		(0.021)		(0.024)		(0.023)	
Trade openness (ordinary trade)		-0.056[b]		-0.029[c]		-0.030		-0.022
		(0.024)		(0.017)		(0.020)		(0.018)
Trade openness (processing trade)		-0.102[a]		-0.074[a]		-0.103[a]		-0.087[a]
		(0.027)		(0.025)		(0.027)		(0.027)
Lagged ln GDP per capita	-0.070	-0.169	0.028	-0.021	-0.057	-0.142	0.101	-0.007
	(0.217)	(0.173)	(0.148)	(0.124)	(0.159)	(0.138)	(0.163)	(0.135)
Capital Abundance (K/E)	0.610	0.404	-0.404	-0.595	-0.181	-0.345	-0.932	-1.115
	(1.150)	(1.085)	(0.786)	(0.761)	(0.849)	(0.820)	(0.914)	(0.835)
ln Land area per capita	0.005[c]	0.005[c]	0.000	-0.000	0.002	0.001	0.000	-0.000
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)
FDI over GDP	-0.009	-0.051	0.035	0.015	-0.066	-0.062	0.047	0.027
	(0.125)	(0.120)	(0.084)	(0.084)	(0.097)	(0.105)	(0.094)	(0.093)
Share of Univ. students over population	-1.793[a]	-1.701[a]	-0.738[b]	-0.666[b]	-1.172[a]	-1.000[b]	-0.900[b]	-0.746[c]
	(0.496)	(0.515)	(0.302)	(0.317)	(0.399)	(0.420)	(0.354)	(0.381)
Employment share in secondary sector	1.524[b]	1.329[b]	0.893[b]	0.844[b]	0.877[b]	0.891[b]	0.995[b]	0.902[b]
	(0.599)	(0.557)	(0.387)	(0.373)	(0.415)	(0.403)	(0.443)	(0.423)
ln Electricity consumption	0.229[a]	0.226[a]	0.153[a]	0.160[a]	0.248[a]	0.268[a]	0.158[a]	0.168[a]
	(0.075)	(0.075)	(0.044)	(0.046)	(0.059)	(0.061)	(0.048)	(0.050)
Technology development area			-0.076	-0.421[c]	-0.078	-0.672[b]	-0.039	-0.518[c]
			(0.179)	(0.241)	(0.245)	(0.284)	(0.221)	(0.275)
City and year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1870	1870	2194	2194	2169	2169	2163	2163
No. of cities	191	191	224	224	221	221	221	221
Partial R^2 of excluded IV	0.032	0.033	0.025	0.024	0.030	0.031	0.023	0.025
Underidentification test	29.66	30.00	27.14	28.00	29.96	31.82	24.44	31.60
Weak identification test	11.87	8.53	9.93	8.63	10.26	9.33	8.80	9.30
Hansen (p-value)	0.49	0.88	0.34	0.76	0.33	0.79	0.30	0.84

Heteroskedasticity-robust standard errors appear in parentheses. [a], [b] and [c] indicate significance at the 1%, 5% and 10% confidence levels. The underidentification test is based on the Kleibergen-Paap rk LM-statistic, with [a] indicating that the p-value (Chi-sq(2)) is below 0.01, suggesting that underidentification is rejected. The weak identification test is based on the Kleibergen-Paap Wald rk F-statistic. The critical value of the Staiger and Stock (2005) F-statistic to assess instrument validity for two endogenous regressors and four instruments is 7.56 for 10% maximal IV relative bias. The Hansen J-statistic is an overidentification test of all instruments. A Chi-sq(2) p-value above 0.10 suggests that the model is overidentified and the instruments are exogenous.

to ordinary trade.

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Appendix

City-level capital stock

The initial capital stocks in 1994 (the first year investment data is available to us) in city c are calculated based on a constant (or steady state) K/Y implied by the capital-accumulation equation given a constant investment rate I/Y and constant growth rates of GDP per capita (Y/L) and population (L):

$$\left(\frac{K}{Y}\right)^{c}_{1994} = \frac{({}^{Ik}/_{Y})^{c}}{g + \delta + n}$$

In this expression, K/Y is the average share of physical investment in output from 1994 through 1997, n represents average population growth over that period, and g and δ represent the average rate of total factor productivity growth and the depreciation rate, respectively. We assume $\delta = 5\%$ and $g = 2\%$, consistent with the literature. We therefore calculate:

$$K^{c}_{1994} = Y^{c}_{1994} \times \frac{({}^{Ik}/_{Y})^{c}_{1994-97}}{0.07 + n_{1994-97}}$$

where $n_{1994-97}$ is average population growth between 1994 and 1997. Given the initial capital stock estimates, the capital stock of city c in period t is given by:

$$K^{c}_{t} = \sum_{j=0}^{t} (1-\delta)^{(t-j)} Ik^{c}_{j} + (1-\delta)^{t} K^{c}_{1994}$$

with Ik^{c}_{j} being gross fixed capital formation of city c in year j.

Table A-1: Summary statistics

	Mean	Std dev.	Min	Max
Trade variables (% of GDP)				
Trade openness	16.86	20.27	0.10	130.79
Domestic VA Trade openness (method 1)	10.52	12.60	0.06	87.17
Domestic VA Trade openness (method 2)	8.74	10.92	0.06	68.82
Domestic Trade openness	10.38	11.85	0.04	89.64
Foreign Trade openness	6.47	11.35	0	93.65
Ordinary Trade openness	11.43	12.94	0.10	100.20
Processing Trade openness	4.26	8.15	0	62.80
Instruments				
ln(Supplier Access)	27.99	0.30	27.21	29.97
Lagged weighted export rebate	0.60	0.24	0.01	0.99
Lagged weighted import tax	8.24	5.78	0.01	44.89
Controls				
Lagged GDP per capita (Yuan)	22,079	21,128	2,217	212,086
Capital Abundance (K/E) (100 billion Yuan per person)	0.06	0.04	0.01	0.27
Land area per capita (km^2 per 10,000 inhabitants)	42.31	47.91	3.87	471.6
FDI over GDP	0.30	0.30	0	1.95
Share of Univ. students over population (per 10 inhabitants)	0.15	0.19	0	1.27
Technology development area	0.23	0.42	0	1
Share of polluting sectors in exports	33.22	25.36	0	100
Share of polluting sectors in imports	20.92	20.64	0	98.81
Observations		2,289		

Table A-2: The impact of trade openness on SO_2 emissions - OLS results

Dependent variable	Ln SO2 emissions per capita			
	(1)	(2)	(3)	(4)
Trade openness ([X+M]/GDP)	-0.001	-0.001	-0.002	-0.002
	(0.002)	(0.002)	(0.002)	(0.002)
Lagged ln GDP per capita	-0.082	-0.085	-0.118	2.497^b
	(0.174)	(0.173)	(0.167)	(1.051)
Capital Abundance (K/E)	-0.490	-0.383	-0.379	-22.126^c
	(0.867)	(0.871)	(0.875)	(12.985)
ln Land area per capita		-0.002	-0.001	-0.003
		(0.003)	(0.002)	(0.003)
FDI over GDP		-0.022	-0.022	-0.023
		(0.071)	(0.070)	(0.067)
Share of Univ. students over population		-0.404	-0.359	0.012
		(0.289)	(0.290)	(0.283)
Technology development area		0.313^a	0.262^a	0.189^a
		(0.063)	(0.068)	(0.070)
Employment share in secondary sector			0.173	0.100
			(0.335)	(0.322)
ln Electricity consumption			0.097^b	0.086^b
			(0.046)	(0.044)
Lagged $[\ln(\text{GDP per capita})]^2$				-0.139^b
				(0.056)
$(K/E)^2$				8.287
				(10.535)
(K/E) × Lagged ln GDP per capita				1.894
				(1.381)
City and year fixed effects	Yes	Yes	Yes	Yes
Observations	2,289	2,289	2,289	2,289
No. of cities	235	235	235	235

Heteroskedasticity-robust standard errors appear in parentheses. ^{a}, ^{b} and ^{c} indicate significance at the 1%, 5% and 10% confidence levels.

Table A-3: The first stage of the estimates in Table 1

Dependent variable:	Trade openness			
	(1)	(2)	(3)	(4)
ln Supplier Access	18.120^{a}	18.705^{a}	18.524^{a}	17.699^{a}
	(3.050)	(3.102)	(3.030)	(3.118)
Lagged weighted export rebate	3.911^{b}	3.810^{b}	2.897	2.814
	(1.733)	(1.772)	(1.807)	(1.815)
Lagged weighted import tax	-0.018	-0.013	-0.024	-0.011
	(0.029)	(0.029)	(0.030)	(0.027)
Lagged ln GDP per capita	-1.244	-0.792	-1.308	-26.046^{c}
	(1.929)	(1.971)	(2.014)	(14.385)
Capital Abundance (K/E)	-1.699	0.027	3.158	448.117^{a}
	(11.174)	(11.399)	(11.429)	(173.627)
ln Land area per capita		0.027	0.041	0.044^{c}
		(0.023)	(0.025)	(0.026)
FDI over GDP		-0.246	-0.028	-0.344
		(1.264)	(1.239)	(1.266)
Share of Univ. students over population		-15.171^{a}	-14.210^{a}	-13.957^{a}
		(3.046)	(3.090)	(3.266)
Technology development area		-9.452^{a}	-10.363^{a}	-9.999^{a}
		(2.804)	(2.740)	(2.817)
Employment share in secondary sector			17.141^{a}	17.843^{a}
			(4.150)	(4.152)
ln Electricity consumption			1.393^{a}	1.342^{a}
			(0.399)	(0.400)
Lagged $[\ln(\text{GDP per capita})]^2$				1.423^{c}
				(0.800)
$(K/E)^2$				198.356
				(136.219)
(K/E) $\times$ Lagged ln GDP per capita				-46.917^{b}
				(19.367)
Observations	2,289	2,289	2,289	2,289
R^2	0.022	0.037	0.053	0.059

Heteroskedasticity-robust standard errors appear in parentheses. ^{a}, ^{b} and ^{c} indicate significance at the 1%, 5% and 10% confidence levels.

Table A-4: The first stage of the estimates in columns 1 to 4 of Table 4

Trade-openness measure	Dom.	For.	Dom.	For.	ODT	PCS	ODT	PCS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln Supplier Access	11.110[a]	1.207	11.278[a]	1.234	10.391[a]	1.271	10.651[a]	1.659
	(2.627)	(2.370)	(2.639)	(2.514)	(2.399)	(2.312)	(2.372)	(2.460)
ln Supplier Access × coast	1.295	5.729[a]	1.034	5.725[a]	1.124	5.509[a]	0.800	5.391[a]
	(1.065)	(1.288)	(1.068)	(1.309)	(0.906)	(1.293)	(0.897)	(1.303)
Lagged weighted export rebate	-2.288[b]	5.519[a]	-2.709[a]	5.273[a]	-0.534	3.021[b]	-0.970	2.716[b]
	(0.934)	(1.195)	(0.974)	(1.231)	(0.782)	(1.197)	(0.802)	(1.222)
Lagged weighted import tax × coast	0.028	0.041	0.024	0.049	0.119[a]	-0.070[c]	0.115[a]	-0.059
	(0.034)	(0.045)	(0.036)	(0.045)	(0.043)	(0.040)	(0.044)	(0.040)
Lagged ln GDP per capita	1.962[b]	-2.938[b]	1.878[c]	-2.915[c]	0.722	-2.402	0.679	-2.433
	(0.984)	(1.483)	(1.009)	(1.536)	(0.789)	(1.545)	(0.782)	(1.611)
Capital Abundance (K/E)	-3.447	-1.160	-0.830	0.451	-5.221	0.165	-4.063	3.586
	(8.006)	(7.264)	(8.360)	(7.481)	(5.270)	(7.477)	(5.531)	(7.676)
ln Land area per capita			0.002	0.030			-0.004	0.035
			(0.008)	(0.024)			(0.006)	(0.023)
FDI over GDP			0.442	0.340			0.086	0.011
			(1.021)	(0.734)			(0.846)	(0.708)
Share of Univ. students over population			-3.510	-11.037[a]			-2.036	-12.518[a]
			(2.295)	(2.010)			(2.067)	(2.346)
Technology development area			-0.457	-9.341[a]			-8.705[a]	-1.124
			(0.839)	(3.210)			(1.911)	(1.458)
Employment share in secondary sector			10.750[a]	4.763[c]			7.755[a]	6.650[b]
			(2.817)	(2.850)			(1.929)	(3.020)
ln Electricity consumption			0.380[b]	1.034[a]			0.570[a]	0.786[a]
			(0.188)	(0.321)			(0.200)	(0.287)
Observations	2,289	2,289	2,289	2,289	2,289	2,289	2,289	2,289
R^2	0.031	0.057	0.044	0.083	0.031	0.036	0.048	0.061

Heteroskedasticity-robust standard errors appear in parentheses. [a], [b] and [c] indicate significance at the 1%, 5% and 10% confidence levels. The dependent variable is Dom., For., ODT or PCS, as indicated in the headings. Trade openness is calculated as the ratio of exports and imports by domestic firms over GDP in columns (1) and (3), and as the ratio of exports and imports by foreign firms in columns (2) and (4). The dependent variable is the ratio of trade openness of ordinary transactions in columns (5) and (7) and the ratio of trade openness of processing transactions in columns (6) and (8).

"Sur quoi la fondera-t-il l'économie du monde qu'il veut gouverner? Sera-ce sur le caprice de chaque particulier? Quelle confusion! Sera-ce sur la justice? Il l'ignore."

Pascal

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