Sources of Comparative Advantage in Polluting Industries*

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Abstract

We study the determinants of comparative advantage in polluting industries by analyzing how country and industry characteristics interact to determine trade flows. We find that countries with weaker environmental regulation export relatively more in polluting industries, consistent with a *pollution haven effect.* Furthermore, this effect is quantitatively important and comparable in magnitude to traditional sources of comparative advantage such as skill and capital abundance. However, these estimates cannot be interpreted as causal: countries with a comparative advantage in polluting industries could have stronger lobbies against environmental regulation. Thus we propose an instrument for environmental regulation based on exogenous meteorological determinants of pollution dispersion identified by the atmospheric pollution science literature. We find that the pollution heaven effect is indeed causal and stronger than suggested by OLS estimates.

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1 Introduction

What are the sources of comparative advantage in polluting industries? This is an old question in the literature on international trade and the environment. Theory provides a straightforward answer. Everything else equal, countries with lax environmental regulation should have a comparative advantage in polluting industries. This result is known as the *pollution haven effect*. Despite its theoretical appeal, there is still no consensus in the empirical literature about its economic relevance.

To address this question, we analyze how country and industry characteristics interact to determine comparative advantage in polluting industries. We find that countries with laxer environmental regulation export relatively more in polluting industries. This effect is quantitatively important and comparable in magnitude to traditional sources of comparative advantage such as skill and capital abundance. However, these estimates cannot be interpreted as causal: countries with a comparative advantage in polluting industries could have stronger lobbies against environmental regulation. Thus we propose an instrument for environmental regulation based on exogenous meteorological determinants of pollution dispersion identified by the atmospheric pollution science literature. We find that the pollution heaven effect is indeed causal and stronger than suggested by OLS estimates.

To guide the empirical work, we begin by presenting a simple model that analyzes the effects of environmental policy on the patterns of international trade. As is standard in the literature on trade and the environment [Copeland and Taylor (2003)], we treat pollution as another factor of production, whose relative supply is determined by environmental policy. We illustrate how countries with lax environmental regulation tend to have a comparative advantage in polluting industries. The model emphasizes the endogenous determination of environmental regulation. In particular, environmental policy depends on technology and income and also on how costly pollution is in each country. The model shows that countries in which pollution is less costly in welfare terms will tend to adopt laxer environmental policy. This result is crucial to motivate our choice of instrument for environmental policy.

Turning to our empirical strategy, we extend the standard cross-country, cross-industry methodology to study the determinants of comparative advantage proposed by Romalis (2004).[1] Specifically, we treat pollution intensity as a technological characteristic of industries, like capital and skill intensity. At the same time, we treat environmental regulation as a characteristic of countries, like capital and skill abundance. We ask whether countries with laxer environmental regulation

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[1] This approach has been used to study a variety of sources of comparative advantage. See, for example, Levchenko (2007), Nunn (2007), Manova (2008), Costinot (2009), Chor (2010), and Cuñat and Melitz (forthcoming).

have a comparative advantage in polluting industries, while controlling for other determinants of comparative advantage. An advantage of this procedure is that it allows us to study the sources of comparative advantage in polluting industries more broadly than existing studies, as we do not focus on particular industries or trading partners.

We find evidence consistent with the pollution haven effect. That is, we show that countries with laxer environmental regulation tend to export relatively more in polluting industries. Furthermore, we find that these effects are quantitatively important. As an example, consider the following thought experiment. Take South Africa, a country with average air pollution regulation stringency in our sample. Now consider the effects of South Africa adopting a more stringent environmental policy, say to the level of France which is one standard deviation above the mean of cross-country regulatory stringency. We find that South Africa's exports to the U.S. in pollution-intensive industries would decrease significantly. For example, relative to South Africa's average market share in the U.S., the share of its exports in steel products manufacturing, which is one standard deviation more pollution intensive than the typical industry, would decrease by 10 percent. Moreover, this effect is comparable in magnitude to more traditional determinants of comparative advantage. In particular, in an analogous experiment, increasing skill (capital) abundance would yield an increase in the relative shares of skill (capital) intensive industries of 7 percent (3 percent).

An important concern regarding the interpretation of the results outlined above is the direction of causality. For example, in countries in which polluting industries are more important they might lobby more successfully to prevent the enactment of strong environmental regulations. This would imply that comparative advantage in polluting industries causes laxer environmental policy, leading to a positive bias. On the other hand, reverse causality could lead to a negative bias if in the face of a heavily polluted environment citizens successfully push for stricter regulation.[2] To address this concern we need an instrument for environmental regulation. That is, a source of variation in environmental regulation that is not determined by comparative advantage in polluting industries (exogenous) and does not affect comparative advantage through other channels (exclusion restriction). To find such an instrument we turn to the large and established literature on the determinants of atmospheric pollution. This literature has identified a number of meteorological variables that determine the speed of dispersion of pollutants. As suggested by the model, our hypothesis is that meteorological conditions that facilitate the dispersion of pollutants in the atmosphere are likely to lead to a lower marginal cost of emissions for a given level of pollution and thus to laxer air pollution regulation.

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[2] For a more thorough discussion of potential problems of reverse causality see Ederington and Minier (2003) and Levinson and Taylor (2008).

Our measure of the speed of air pollution dispersion is the "ventilation coefficient." This coefficient is the product of two exogenous meteorological determinants of pollution dispersion in the atmosphere: wind speed, which determines horizontal dispersion of pollution, and mixing height, which determines the height within which pollutants disperse in the atmosphere. The ventilation coefficient is the main determinant of pollution dispersion according to the standard Box model of atmospheric pollution. This model thus provides us with a simple metric to assess and compare the potential for pollution dispersion across countries: given two countries with the same level of emissions the country with the higher ventilation coefficient will have lower pollution concentration.

The instrumental variable estimates of the effect of environmental regulation on comparative advantage in polluting industries are around 80% higher than OLS estimates. This finding points towards two sources of bias in the OLS estimates. First, OLS estimates can be biased downwards if countries with a comparative advantage in polluting industries face stronger demand from their citizens to address air pollution problems and thus enact stricter regulation. Second, our measure of environmental regulation captures a single dimension of policy, thus OLS estimates might be downward biased due to measurement error.

We contribute to a rich literature studying the role of environmental regulation on comparative advantage. Early studies focused on establishing *cross-country* trends. Between 1960 and the early 1990's pollution-intensive output as a percentage of total manufacturing fell in the OECD and increased in the developing world. In addition, those periods of rapid increase in net exports of pollution-intensive products from developing countries coincided with periods of rapid increase in the cost of pollution abatement in OECD countries.[3] Although consistent with the pollution haven effect, these trends could also be accounted for by other mechanisms. For example, capital accumulation in developing countries could lead to an increasing comparative advantage in capital-intensive goods, which only happen to be polluting.

More recent studies have sought to establish a direct link between environmental regulation, the location of polluting industries, and the resulting pattern of trade. These papers emphasize the *cross-industry* variation in U.S. environmental regulation and use pollution abatement costs as a proxy for regulation at the industry level. The first studies did not find strong effects of abatement costs on trade flows [Grossman and Krueger (1993)].[4] In contrast, Levinson and Taylor (2008) find that industries whose abatement costs increased more experienced larger increases in imports when

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[3] See Jaffe et al. (1995), and Mani and Wheeler (1999). These trends have accelerated since the early 1990s. For example, sulfur dioxide emissions have been reduced by half in both the US and Europe since the early 1990s (see United States Environmental Protection Agency Clearinghouse for Inventories and Emissions Factors and European Environmental Agency). On the other hand, sulfur dioxide emissions in China are estimated to have increased by 50% between 2000 and 2006 (see Lu et al., 2010).

[4] For a survey of the literature, see Copeland and Taylor (2004).

instrumenting for pollution abatement costs.[5] However Ederington, Levinson and Minier (2005) find that increases in abatement costs increase imports only in footloose industries, which happen to be the least polluting ones. In contrast, we find that differences in environmental regulation across countries have strong effects on exports of polluting industries.

Finally, let us note that we find that countries weak environmental regulation have a comparative advantage in polluting industries even without controlling for other sources of comparative advantage. This result, referred to in the literature as the *pollution haven hypothesis*, is usually considered to be stronger than the *pollution haven effect*.[6] As countries with weak environmental regulation are usually capital scarce and capital intensive sectors tend to be polluting, there is potentially an effect going in the opposite direction: capital abundant countries could specialize in polluting industries. Our evidence suggests that the magnitude of the pollution heaven effect is large enough to dominate this potentially countervailing effect.[7] The evidence in this paper also helps reconcile the effects of environmental regulation on international trade flows, traditionally viewed as weak, with a large body of evidence documenting a strong effect of environmental regulation on plant location and FDI flows.[8]

The paper is organized as follows. Section 2 presents the theoretical model. Section 3 describes the data. Section 4 presents our OLS empirical results. Section 5 describes our meteorological instrument. Section 6 presents the instrumental variable results. Section 7 concludes.

2 Pollution and environmental regulation in a standard model of trade

In this section we present a simple model that illustrates how environmental policy and income affects comparative advantage in polluting industries. It also shows how ventilation potential and income, in turn, affect environmental policy.

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[5] As Levinson and Taylor (2008) point out, the use of pollution abatement costs presents a number problems. In particular, compositional effects within industries might make pollution abatement costs a poor proxy for policy. Also, environmental regulation at the industry level may be endogenous due to political economy factors. These problems can result in a variety of biases that may explain the negative results. Indeed, when Levinson and Taylor (2008) account for the endogeneity of environmental regulation they find a positive effect of changes in pollution abatement costs between 1977 and 1986 on changes in U.S. imports from Mexico and Canada. See also Ederington and Minier (2003).

[6] For a more detailed discussion of the *pollution haven hypothesis* and the *pollution haven effect* see Copeland and Taylor (2004).

[7] Still, it is important to emphasize that even the *pollution haven hypothesis* does not imply that international trade with countries with weak environmental regulation should increase global pollution. In particular, several papers have argued that trade liberalization can lead to growth which in turn might induce countries to enact more stringent environmental regulation or adopt cleaner technologies [Grossman and Krueger (1993), Antweiler, Copeland, and Taylor (2001), and Levinson (2009)].

[8] See for example Becker and Henderson (2000), Greenstone (2002), Keller and Levinson (2002) and List et al. (2003).

2.1 Setup

There are many small countries, indexed by $j \in J$. Labor is the only factor of production. There is a mass one of residents in every country, each endowed with L units of labor. There are two goods, one *clean* and one *dirty*, both of which are tradable. Production of the clean good requires labor and does not pollute. Labor productivity in country j is A_j, so that

$$Q_{cj} = A_j \cdot L_{cj},$$

where Q_{cj} is production of the clean good and L_{cj} is labor allocated to the clean industry. Production of the dirty good does not require labor but is polluting. In particular, each unit of the dirty good produces $A_j^{-\gamma}$ units of pollution, so that

$$Q_{dj} = A_j^{\gamma} \cdot Z_{dj},$$

where Q_{dj} is production of the dirty good and Z_{dj} is pollution produced in the dirty industry. The parameter $\gamma \in [0, 1]$ captures the extent to which countries with higher productivity also have access to better abatement technologies. Factor market clearing implies that

$$Q_{cj} = A_j \cdot L_{cj} = A_j \cdot L \quad \text{and} \quad Q_{dj} = A_j^{\gamma} \cdot Z_{dj} = A_j^{\gamma} \cdot Z_j,$$

where Z_j is total pollution produced in country j.[9]

Utility is increasing in consumption of the clean and dirty goods and decreasing in pollution. We assume that pollution only affects utility in the country where it is produced. In particular, utility in country j is

$$U\left(C_{cj}^{\alpha_c} \cdot C_{dj}^{\alpha_d}\right) - V\left(\phi_j \cdot Z_j\right), \tag{1}$$

where $\alpha_c + \alpha_d = 1$, $U' > 0$, $U'' < 0$, $V' > 0$, $V'' > 0$, and ϕ_j measures how costly in utility terms is pollution in country j. The parameter ϕ_j is inversely related to the ventilation potential of country j. In particular, meteorological conditions that facilitate the dispersal of pollutants will be associated with a low ϕ_j.

Producing the dirty good is associated with a negative local externality. Countries address this externality by imposing pollution limits.[10] In particular, in each country j there is a cap on

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[9] Our treatment of pollution as another factor in the production process is standard in the literature on trade and the environment. See Copeland and Taylor (2003) for a textbook analysis.

[10] In the literature environmental policy is often modeled as a pollution tax. In this model pollution taxes would have effects that are too extreme. The reason is that countries would produce either zero or an infinite amount of the dirty good depending on whether $A_j^{\gamma} \cdot P_d$ is lower or higher than the tax. In reality, environmental policy often

pollution,

$$Z_j \leq \bar{Z}_j, \tag{2}$$

that is implemented by distributing $\bar{Z}_j$ pollution rights to each resident of j. Each country chooses its optimal pollution limit taking those of the other countries as given.[11]

2.2 Equilibrium

To obtain the equilibrium we proceed in two steps going backwards. First, we solve the model for a given pattern of pollution limits $\bar{X}_j$ for $j \in J$. Second, we find the equilibrium pollution limits, which are chosen optimally by each country.

The first step is very simple. Given pollution limits, the model is isomorphic to a two-good, two-factor model in which pollution is a second factor of production as opposed to a by-product.[12] Since the price of the dirty good is positive, Constraint (2) is binding and production is given by

$$Q_{cj} = A_j \cdot L \ \text{ and } \ Q_{dj} = A_j^{\gamma} \cdot \bar{Z}_j \ \text{ for } \ j \in J. \tag{3}$$

Let P_c and P_d be the prices of the clean and dirty goods respectively. For any P_c and P_d, country j produces $A_j \cdot L$ units of the clean good and $A_j^{\gamma} \cdot \bar{Z}_j$ units of the dirty good. Given Cobb-Douglas preferences, consumption is given by

$$C_{ij} = \frac{\alpha_i \cdot \left(P_c \cdot A_j \cdot L + P_d \cdot A_j^{\gamma} \cdot \bar{Z}_j \right)}{P_i} \ \text{ for } \ i \in \{c, d\}. \tag{4}$$

Integrating this equation over all countries for the clean good and imposing the market clearing condition $\int_{j \in J} C_{cj} = \int_{j \in J} A_j \cdot L$, we obtain the relative price of the dirty good

$$\frac{P_d}{P_c} = \frac{\alpha_d \cdot \int_{j \in J} A_j \cdot L}{\alpha_c \cdot \int_{j \in J} A_j^{\gamma} \cdot \bar{Z}_j}. \tag{5}$$

Normalizing prices so that the price of the "composite good" $C_{cj}^{\alpha_c} \cdot C_{dj}^{\alpha_d}$ is one, we obtain

$$P_c = \alpha_c \cdot \left(\frac{\int_{j \in J} A_j^{\gamma} \cdot \bar{Z}_j}{\int_{j \in J} A_j \cdot L} \right)^{\alpha_d} \ \text{ and } \ P_d = \alpha_d \cdot \left(\frac{\int_{j \in J} A_j \cdot L}{\int_{j \in J} A_j^{\gamma} \cdot \bar{Z}_j} \right)^{\alpha_c}. \tag{6}$$

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takes the form of quantity limits as countries impose restrictions on the location and size of different industries. Also, policy often responds more strongly when the concentration of pollutants in the air reaches certain limits.

[11] The equilibrium in this model is efficient even though countries are small because the externalities are local. This would not be the case for pollutants associated with global externalities, most notably green house gases.

[12] The second term in Equation (1) can be disregarded in this step as, given pollution limits, it is equal to the constant $V\left(\phi_j \cdot \bar{Z}_j\right)$.

With this normalization, welfare is given by

$$U\left(I_j\left(\bar{Z}_j\right)\right)-V\left(\phi_j\cdot\bar{Z}_j\right)\quad\text{for}\quad j\in J, \tag{7}$$

where $I_j\left(\bar{Z}_j\right)\equiv P_c\cdot A_j\cdot L+P_d\cdot A_j^{\gamma}\cdot\bar{Z}_j$ is income. Equations (3), (4), (6), and (7) describe the equilibrium for a given pattern of pollution limits $\bar{Z}_j$ for $j\in J$.

Since countries are small, we can analyze the effects of changes in country characteristics taking as given goods prices. In particular, consider an increase in pollution limits $\bar{Z}_j$. Equations (3) and (4) show that Q_{cj} is unaffected and Q_{dj}, C_{cj}, and C_{dj} increase. As a result, exports of the clean good, $Q_{cj}-C_{cj}$, decrease and exports of the dirty good, $Q_{dj}-C_{dj}$, increase. The following result follows.

Result 1. *An increase in pollution limits $\bar{Z}_j$ leads to more comparative advantage in the dirty good.*

We now turn to the determination of pollution limits $\bar{Z}_j$ for $j\in J$. Country j chooses $\bar{Z}_j$ to maximize its welfare in Equation (7), taking as given goods prices P_c and P_d. The optimum $\bar{Z}_j^*$ is determined implicitly by the first order condition

$$0=P_d\cdot A_j^{\gamma}\cdot U'\left(I_j\left(\bar{Z}_j^*\right)\right)-\phi_j\cdot V'\left(\phi_j\cdot\bar{Z}_j^*\right). \tag{8}$$

This conditions shows that countries trade off the increase in income associated with an additional unit of pollution with the utility cost of the additional pollution.

How does $\bar{Z}_j^*$ depend on pollution cost ϕ_j? Once again, since countries are small we can analyze the effect of ϕ_j taking as given goods prices. Take the total derivative of Equation (8) with respect to ϕ_j and rearrange to obtain

$$\frac{d\bar{Z}_j^*}{d\phi_j}=\frac{-V'\left(\phi_j\cdot\bar{Z}_j^*\right)-\phi_j\cdot\bar{Z}_j^*\cdot V''\left(\phi_j\cdot\bar{Z}_j^*\right)}{\phi_j^2\cdot V''\left(\phi_j\cdot\bar{Z}_j^*\right)-P_d^2\cdot A_j^{2\cdot\gamma}\cdot U''\left(I_j\left(\bar{Z}_j^*\right)\right)}.$$

Given the properties of $U\left(\cdot\right)$ and $V\left(\cdot\right)$, it is clear that the numerator is negative and the denominator is positive. The following result follows.

Result 2. *An increase in pollution cost ϕ_j leads to lower pollution limits $\bar{Z}_j$,*

$$\frac{d\bar{Z}_j^*}{d\phi_j}<0. \tag{9}$$

The intuition is straightforward. A higher ϕ_j means that the country is willing to accept less consumption of goods in exchange for lower pollution levels, leading to more stringent environmental standards.

How does $\bar{Z}_j^*$ depend on productivity A_j? In principle, this effect is ambiguous because there are two opposing effects. On the one hand, a higher A_j has an income effect that leads to lower pollution limits, as the country wants to increase its consumption of "clean air." On the other hand, a higher A_j has a substitution effect that leads to higher pollution limits since producing the dirty good becomes less polluting. The latter effect, of course, depends on γ. In the appendix we show the following result.

Result 3. *An increase in productivity A_j has an ambiguous effect on pollution limits $\bar{Z}_j$. However, the effect is unambiguously negative,*

$$\frac{d\bar{Z}_j^*}{dA_j} < 0, \tag{10}$$

if either (i) $\gamma = 0$, or (ii) the coefficient of relative risk aversion $-c \cdot U''(c)/U'(c) > 1$.

The first condition is due to the fact that the substitution effect disappears if $\gamma = 0$. The second condition is due to the fact that, even if $\gamma = 1$, the income effect dominates the substitution effect when the coefficient of relative risk aversion is greater than 1.

The analysis in this section has clear empirical predictions. First, conditional on other country characteristics, countries with less stringent environmental policy have a comparative advantage in polluting industries. Second, environmental policy is less stringent in countries with high ventilation potential. In addition, environmental policy is likely to be more stringent in richer countries.

3 Data

In this section we introduce measures of an industry's air pollution intensity and the strictness of a country's air pollution regulations. We describe each of these measures in detail below and then combine them with U.S. bilateral trade flows to take a first look at the evidence: is cross-country variation in the strictness of air pollution regulations an important determinant of comparative advantage in polluting industries?

The remaining sources of data used in the paper are standard in the literature. The data on bilateral trade flows with the U.S. is from Feenstra, Romalis and Schott (2002), updated till 2006. We source data on cross-country stocks of human capital and physical capital from Hall and Jones (1998). Data on skill and capital intensity at the industry level is available for the manufacturing sector only and is sourced from Bartelsman and Gray's (1996) NBER-CES manufacturing data, updated to 2005.

3.1 A measure of air pollution intensity

Our measure of air pollution intensity at the industry level is drawn from data compiled by the U.S. Environmental Protection Agency's (EPA) in their Trade and Environmental Assessment Model (TEAM).[13] TEAM's air emissions baseline data is based on the EPA's 2002 National Emissions Inventory.[14] From this data set, we obtain - for a host of air pollutants - the total amount of air pollution emitted by 4-digit NAICS industries in the US in 2002. Throughout, we focus our analysis on industry level emissions data of three common air pollutants: Carbon Monoxide (CO), Nitrogen Oxides (NOx) and Sulfur Dioxide (SO2).

Given information on the value of sales in each industry we can then compute the corresponding pollution emission intensity (per dollar of sales in a given industry). In total, we have pollution intensity data for 86 manufacturing industries.[15] Within manufacturing, metal manufacturing, mineral (non-metallic) products manufacturing, paper manufacturing, chemical manufacturing and petroleum and coal products make it to the top of the list in every pollutant ranking displayed in Table 1.

Our list of most pollution intensive manufacturing industries is broadly consistent with the ranking "dirty industries" in Mani and Wheeler (1999) which uses an alternative indicator of pollution intensity based on the Industrial Pollution Projection System (IPSS) data set assembled by the World Bank.[16,17] More generally, as Hettige et al (1995) had noted for IPSS data, there is extreme sectorial variation in emission factors, the distribution being very fat tailed. As an example, the least pollution intensive manufacturing sector in Carbon Monoxide - Tobacco manufacturing- is 24 times less polluting than the most CO intensive industry within manufacturing, Alumina and aluminum production. The upshot of this is that the ten most pollution intensive manufacturing sectors account for a significant amount of total manufacturing air pollution emissions in every

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[13] This data is assembled by the EPA and Abt Associates. See Abt Associates (2009) for a complete description.

[14] Specifically, for each pollutant, we sum across point (i.e. those deriving from large polluting facilities), area and mobile source measurements at the national level.

[15] Given our focus on manufacturing industries we do not exploit information on 180 service sector industries and 28 agriculture and mining industries.

[16] The IPPS data also gives pollution intensity per sector across a range of pollutants. However this data refers to 1987 measurements. Thus our EPA-TEAM data is based on a newer vintage data. Furthermore, as Abt Associates (2009) note, the data used in developing the IPPS pollutant output intensity coefficient, and the 1987 Toxic Release Inventory (TRI) database in particular, "have been the subject of substantial concerns regarding their reliability. This [1987] was the first year the TRI data were self-reported by facility. A 1990 EPA report found that 16 percent of releases reported in the 1987 database were off by more than a factor of ten, and 23 percent were off by a factor of two."

[17] At this degree of sectoral disaggregation, it is difficult to find comparable data for other countries. Still, Cole et al (2004) and Dean and Lovely (2008), when reporting 3-digit ISIC manufacturing pollution intensities for, respectively, the UK during the 1990s and China in 1995 and 2004, single out the same highly polluting industries as we do here: metal manufacturing, non-metallic mineral products, coke and petroleum and paper manufacturing. Reliable data at this more aggregated level is available for at least a handful more of European countries and Canada. In the future we plan to conduct a more systematic cross-country comparison of pollution intensity measures at the industry level.

pollutant, ranging from 38% for CO to 66% in SO2. Further, despite differences in the exact ordering of sectors across pollutant categories, computing a rank correlation reveals a high average correlation: highly pollution intensive industries in a given pollutant tend to be pollution intensive in all pollutants (see Table 2). Table 3 reports the correlation of our measures of pollution intensity and industry level factor intensities of production (skill and capital intensity). Across all pollutants, pollution intensive industries tend to be capital intensive and unskilled intensive[18].

3.2 A measure of air pollution regulation

Our measure of air pollution regulation is grams of lead content per liter of gasoline, a standard measure of environmental stringency and previously used by, for example, Hilton and Levinson (1998), Damania, List and Frederiksson (2003) and Cole, Elliot and Fredriksson (2006).

As Hilton and Levinson (1998) and Lovei (1998) discuss, lead emissions are one of the most toxic substances to which populations around the world have been exposed to, posing severe health problems ranging from cardiovascular diseases to significant reductions in the I.Q. of children exposed to it. As a result, both national environmental agencies and international organizations have targeted reduction in lead emissions. Lead is defined by the E.P.A. as a criteria air pollutant (since 1976) and both the World Bank and the United Nations Environment Program have been actively involved in supporting national environmental policies that address lead pollution.

The largest source of lead exposure has traditionally been tail-pipe emissions from vehicles fueled by leaded fuel. As a result, policies targeting lead pollution in the atmosphere have taken the form of legislation on the lead content of gasoline. Thus, we source cross-country data on the average lead content (in grams) per liter of gasoline from the World Bank (Lovei, 1998) which in turn collects data from industry and consulting sources, World Bank reports and through direct contact of government officials.[19] From this, we obtain lead content data for 101 countries in 1996. Our policy measure ranges from 0 - reflecting a ban on leaded gasoline in countries like Sweden or Denmark - to 0.85 grams per liter of gasoline in Venezuela. A list of the ten least and ten most stringent regulation countries according to this measure is provided in Table 4.

While admittedly narrow and applying primarily to the transportation sector, lead content per gallon of gasoline is, to the best of our knowledge, the only actual air pollution regulation measure

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[18] The positive correlation between pollution intensive and capital intensive industries is again in accordance with the discussion of Mani and Wheeler (1999) for the IPSS dataset. See also Antweiler et al (2001).

[19] While the extant literature as extensively used the lead content policy measure, the source of our lead content data is novel. The literature has traditionally sourced the data from Associated Octel Ltd., the main commercial producer of ethyl lead compounds up until recently. The World Bank technical report from which we source our data (Lovei, 1998) cross-checks and supplements Octel's data with a number of industry publications, World Bank sources and through contacts with government officials.

available for a broad cross-section of countries. Further, as Damania et al (2003) discuss, this variable correlates well with other proxies for the environmental stance of a country such as the environmental stringency index put forth by Dasgupta et al (2001), public expenditure on environmental R&D as a proportion of GDP or per capita membership of environmental organizations. Our lead content measure is also negatively correlated with other traditional determinants of comparative advantage like capital and skill abundance[20]. This is as expected and reflects the fact that richer countries have tended to spearhead efforts in addressing atmospheric lead pollution. Thus, the correlation of grams of lead per liter of gasoline with log income per capita is -0.63 and significant at the 1% level. Still, as Lovei (1998) notes, governmental policies in several middle and low income countries have also contributed to stringent policy being enacted in parts of the developing world. This is the case of Bolivia or Thailand for example. This suggests that our measure captures actual policy stringency and not simply the income of a country.

4 Determinants of Comparative Advantage in Polluting Goods

In this section we investigate whether lax environmental regulation can be a source of comparative advantage in polluting goods. Anticipating the more detailed empirical analysis below, and as a first look at the raw data, we ask whether the share of exports in pollution intensive industries is larger for countries with weak air pollution regulations. To do this, we divide the sample into weak versus strict air pollution regulation countries, defined as those with a measure of lead content of gasoline, respectively, above and below the sample median. Similarly, we group industries into those that are pollution intensive and those that are not. We define an industry to be pollution intensive in a given pollutant if the corresponding if is in the top quartile of the distribution of total pollution intensities for that pollutant. We find that, for weak regulation countries, 51 percent of their manufacturing exports to the US are in NOx intensive industries while for strict air pollution regulation counties only 28 percent of exports are in NOx intensive industries. The pattern repeats itself for SO2 (48 versus 29 percent respectively) and CO (51 versus 31 percent respectively). Thus, countries with weak air pollution regulations tend to export relatively more in pollution intensive industries to the US.

Next, we conduct a more systematic analysis of the effects of environmental regulation on exports of polluting goods. For this purpose, we incorporate environmental regulation as a country characteristic and pollution intensity as an industry characteristic in a standard cross-country cross-industry trade equation. In our model, regulation is implemented as a quantity restriction

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[20] The correlation is -0.64 for capital abundance and -0.69 for skill abundance. Both are significant at the 1% level.

and it thus immediately admits a factor abundance interpretation. We thus treat environmental regulation in the same way that we treat capital and skill abundance. The model also illustrates how pollution can be interpreted as another input in production. We thus treat pollution intensity in the same way that we treat capital and skill intensity.[21]

Our empirical specification takes the form

$$M_{ic} = \beta_1 \; E_c \times z_i + \beta_2 \; K_c \times k_i + \beta_3 \; H_c \times h_i + \alpha_c + \alpha_i + \varepsilon_{ic}, \tag{11}$$

where M_{ic} are country c´s relative import shares into the U.S. in industry i, described in further detail below; E_c is a measure of the laxity of air pollution regulation in country c; z_i is a measure of the pollution intensity of industry i; K_c and H_c denote country c´s endowments of capital and human capital; k_i and h_i are industry i´s capital and skill intensity; α_c and α_i are country and industry fixed effects.[22] Result (1) in Section 2, namely that a country with laxer environmental regulation should export relatively more in polluting industries, would correspond to finding $\beta_1 > 1$.

Our dependent variable, country c´s relative import shares (M_{ic}) into the U.S., is defined as country c´s trade share in sector i divided by the average share of country i in U.S. imports. This normalization, suggested by Levchenko (2007), aims at making trade shares comparable across countries by accounting for heterogeneity in country size and the closeness of the trade relationship with the U.S. Alternatively, we could use a log-transformation of imports but this has the disadvantage of dropping the observations with zero trade, around one third of the total. We thus prefer the specification in shares. Still, we obtain similar coefficient estimates both in terms of magnitude and statistical significance when using the log of imports as our dependent variable, as we report in Appendix 3.

For industry factor intensities, we use U.S. factor shares in value added. Since there is no comparable measure of pollution share in value added, we use the quantity of pollution emitted by each industry divided by the value added of that industry in the U.S., i.e. $z^i_{US} = Z^i_{US} \big/ \left(Q^i_{US} \cdot p^i_{US} \right)$. Under the assumption that all industries face the same effective price of pollution τ_{US}, this procedure does not lead to biases in the estimation of Equation (11) because the use of z^i_{US} amounts to dividing the pollution share by a constant. Overall, this specification is correct if, as we assumed in the model, differences across countries in technology and environmental policy do not affect the relative pollution intensities of industries.

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[21] Under some conditions, these interpretations are also appropriate in models in which regulation is implemented as a pollution tax. See Copeland and Taylor (2003) for details.

[22] This specification is an extension of the one used by Romalis (2004). Similar extensions have been used to explore a variety of sources of comparative advantage by Levchenko (2007), Nunn (2007), Manova (2008), Costinot (2009), Chor (2010), and Cuñat and Melitz (forthcoming).

4.1 Baseline Results

As measures of pollution intensity we use the simple average of pollution emitted per unit of output for three air pollutants sulfur dioxide (SO2), nitrogen oxides (NOx) and carbon monoxide (CO). Table 5 reports estimation of Equation (11) for the average pollution intensity measure and also for each of the three air pollutants separately, without controlling for capital and skill interactions. The first row reports the estimate of β_1 for the interaction of pollution intensity of the industry with the lax air pollution regulation measure. The remaining columns report the analogous estimation for the rest of the pollutants. The estimated β_1 coefficient on the air pollution regulation and air pollution intensity interaction ($E_c \times z_i$) are positive and statistically significant at 1 percent for each pollutant and the pollution intensity index. The estimated coefficient on the pollution interaction ($E_c \times z_i$) reported in column 1 implies that if a country moves from the mean to a one standard deviation below the mean in air pollution regulation, the predicted relative import share of an industry that is one standard deviation above the mean pollution intensity increases by 6.24% of a standard deviation. In addition, their effects are of a similar magnitude.[23] Thus, to simplify the exposition, in what follows we only report estimates for the air pollution intensity index. Like Table 5, all subsequent tables report robust standard errors below coefficient estimates. To address potential correlation in errors across industries or countries, we show in Appendix 3, that the estimated coefficients are also statistically significant when clustering errors across countries, industries and both countries and industries.

Estimation of Equation (11) with controls for factor endowments and other determinants of comparative advantage is reported in Table 6. Note that as measures of capital and skill endowments are only available for a subset of countries, the sample is smaller than in Table 5. Columns 1 and 2 show that adding controls for capital and skill interactions ($K_c \times k_i$ and $H_c \times h_i$) does not significantly affect the estimated coefficients, which suggests that the environmental regulation and pollution intensity interaction ($E_c \times z_i$) is not capturing other classical determinants of comparative advantage. In addition, the magnitude of the effect of the pollution intensity interaction is similar to the factor intensity interactions. The estimated coefficient on the on the pollution interaction ($E_c \times z_i$) reported in column 2 implies that if a country moves from the mean to a one standard deviation below the mean in air pollution regulation, the predicted relative import share of an industry that is one standard deviation above the mean pollution intensity increases by 8.3% of a standard deviation. The equivalent estimates for the capital intensity and skill intensity interactions are 5.15% and 6.6%.

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[23] Note that we report beta coefficients, thus estimates for different pollutants are directly comparable.

4.2 Robustness

A potential problem in the estimation of Equation (11) is that environmental regulation is partially determined by other country characteristics. In particular, it is possible that richer citizens demand more stringent environmental regulation [Grossman and Krueger (1993), Copeland and Taylor (1994)]. Alternatively, it is possible that countries with better legal institutions are more efficient at enforcing environmental regulation. This leads to a positive correlation between environmental regulation and those country characteristics. If pollution intensity is also correlated with other industry characteristics, the omission of these other determinants of comparative advantage can bias the estimated effect of environmental regulation on comparative advantage.

We follow two different strategies to address these concerns. First, we estimate Equation (11) including controls for other sources of comparative advantage. For example, if developed countries tend to have more stringent environmental regulation and polluting industries tend not to be the most technologically advanced, we need to control for the possibility that more technologically advanced countries specialize in R&D intensive industries. Thus, we include an interaction between GDP per capita and industry-level TFP growth. This does not significantly affect the estimated coefficient on the pollution interaction, as reported in Columns 2, 3 and 4 of Table 6. Another important concern is that the environmental interaction could be capturing the effect of oil abundance on exports of oil-intensive goods: polluting industries might also be oil-intensive and oil-abundant countries might implement lax environmental regulation. Column 5 shows that our coefficient estimate is robust to including a control for an interaction of country´s oil abundance and industry´s oil-intensity.[24] Finally, we also control for institutional determinants of comparative advantage. In particular, the recent trade literature (Antras, 2003, Nunn, 2007, Levchenko, 2007, Costinot, 2009) has highlighted the role of contracting institutions for the production and trade of products for which relationship-specific investments are important. Columns 6 and 7 show that the estimated coefficient on the pollution interaction remains stable statistically significant at 1% after the inclusion of an interaction of the efficiency of legal institutions and the measure of contracting intensity of the industry developed by Nunn (2007).[25]

A potential problem with the first strategy to deal with omitted sources of comparative advantage discussed above is that we do not have precise measures for all the industry characteristics that might be correlated with pollution intensity. Thus, the interaction of environmental regulation

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[24] We compute oil-intensity at the industry-level using data on the value share of crude oil as an input in production from the U.S. input-output matrix. We measure oil abundance as oil reserves per capita.

[25] As a measure of the efficiency of legal institutions we use the total number of procedures mandated by law or court regulation that demand interaction between the parties or between them and the judge or court officer from World Bank (2004).

with pollution intensity might still capture the effects of other country-level variables on comparative advantage. We follow a second strategy to address this concern. Table 7 shows that the estimated coefficient on the interaction of environmental regulation and pollution intensity remains positive, stable and statistically significant at 1% after the inclusion of controls for interactions of pollution intensity with the following country-level variables: income per capita, fertile land per capita, capital abundance, skill abundance, oil abundance and the efficiency of legal institutions. These results suggest that environmental regulation is not capturing the effect of other country characteristic that influences comparative advantage in polluting industries.

5 An Instrument for Environmental Policy

In the previous section, we showed that countries with laxer environmental regulation have a comparative advantage in polluting industries. However, this does not necessarily mean that causality runs from regulation to comparative advantage. For example, in countries in which polluting industries are more important these industries might lobby more successfully to prevent the enactment of strong environmental regulations. This would imply that comparative advantage in polluting industries causes laxer environmental policy, leading to a positive bias. On the other hand, reverse causality could even lead to a negative bias if in the face of a heavily polluted environment citizens successfully push for stricter regulation.[26] Moreover, our measure of environmental regulation is potentially an imperfect proxy since it only measures one dimension of the regulatory spectrum. This can result in measurement error, which would also lead to a negative bias.

To address this problem, in this section we propose an instrument for environmental regulation. To do so, we turn to the large and established literature on the determinants of atmospheric pollution. This literature has identified a number of meteorological variables that determine the speed of dispersion of pollutants. Our hypothesis is that meteorological conditions that slow the dispersion of pollutants are likely to lead to the adoption of stricter environmental regulation. We next describe briefly the science behind our choice of meteorological variables. We then describe in detail the data sources and provide some broad stylized facts about these variables.

5.1 Meteorological determinants of pollution

It has long been recognized that meteorological conditions affect air pollution transport and its dispersion in the atmosphere. For a given amount of emissions at a location, the resulting con-

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[26] For a more thorough discussion of potential problems of reverse causality see Ederington and Minier (2003) and Levinson and Taylor (2008).

centration of pollutants is determined by winds, temperature profiles, cloud cover, and relative humidity, which in turn depend on both small- and large-scale weather systems. (See Jacobson, 2002, for a textbook treatment). Further, when meteorological conditions are such that pollution dispersion is limited, acute air pollution episodes are likely to occur posing significant risks to human health.[27]

As a result, air pollution meteorology is an integral part of environmental policy and monitoring. In the U.S., for example, the E.P.A. routinely resorts to meteorological models both to monitor air quality and to predict the impact of regulation and new sources of air pollution.[28] State-of-the-art atmospheric dispersion models typically combine a sophisticated treatment of physical and chemical processes with background environmental characteristics, detailed inventories on source pollutants, and the geology and geography of the terrain. For the purposes of this paper, we focus on a small set of exogenous variables identified by this literature as the main meteorological determinants of air pollution concentration.[29]

To this effect we resort to an elementary urban air quality model, widely studied in the literature, the so-called Box model. This model takes into account the two main forces acting on pollutant dispersion. First, pollution disperses horizontally as a result of wind. Higher wind speed leads to faster dispersion of pollutants emitted in urban areas to areas away from it. Second, pollution disperses vertically as a result of vertical movements of air, which result from temperature and density vertical gradients. In a nutshell, if a parcel of air is warmer than the air surrounding it, the warmer air will tend to rise as a result of its lower density. This continues until the parcel of air rises to a height where its temperature coincides with that of the surrounding air. The height at which this happens is known as the mixing height.[30] This process results in air being continuously mixed in the vertical space between ground level and the mixing height. As a result, the higher the mixing height the greater the volume of air above an urban area into which pollutants are dispersed.

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[27] A textbook example is that of the steel town of Donora, Pennsylvania where in 1948 a week-long period of adverse meteorological conditions prevented the air from moving either horizontally or vertically. As local steel factories continued to operate and release pollutants into the atmosphere 20 people died. (EPA 2005, p.3).

[28] Meteorological models are inputs into air quality models. Under the Clean Air Act, the "EPA uses air quality models to facilitate the regulatory permitting of industrial facilities, demonstrate the adequacy of emission limits, and project conditions into future years" (EPA (2004, pp. 9-1). Further, air quality models "can be used as part of risk assessments that may lead to the development and implementation of regulations." (2004, pp. 9-1).

[29] Including more information - as prescribed by these sophisticated air pollution dispersion models - would not necessarily be of help for the purposes of this paper. First, the demand on data inputs alone would preclude cross-country comparisons as many developing countries simply do not have such detailed information. Second, and more importantly these detailed models include variables that are clearly endogenous from our perspective such as the current flow of pollution and the array of environmental policies in place.

[30] To be precise, the warm parcel of air cools as it ascends since it expands due to the drop in atmospheric pressure. If the rate at which the rising air parcel cools –known as the adiabatic lapse rate– is faster than the rate at which the surrounding air cools –the environmental lapse rate– there exists a height at which their temperature will coincide and the parcel will stop rising. This is the mixing height. (See E.P.A., 2005, or Jacobson, 2002, pp. 157-165.)

In its simplest form, the model predicts pollution concentration levels inside a three-dimensional box. The base of the box is given by a square urban land area of edge length L, which emits Q units of pollution per unit area. The height of the box is the mixing height h. Pollutants enter the box as a result of local emissions and pollutants are assumed to disperse vertically instantaneously. Wind is perpendicular to one of the sides of the box and its speed is u. Pollutants leave the box as part of dirty air through its downwind side. It is assumed that the air entering the box through its upwind side is clean. As explained in the appendix, this means that the total amount of pollution within the box follows a simple differential equation. In steady state, the average concentration of pollution in the urban area is given by

$$C = \frac{L}{2} \cdot \frac{Q}{u \cdot h}. \tag{12}$$

The product of wind speed and mixing height, $u \cdot h$, is known in the literature as the "ventilation coefficient".[31] The average concentration of pollution in the urban area is inversely proportional to its ventilation coefficient.[32] The Box model thus provides a simple metric to assess and compare the potential for pollution episodes across urban areas: given two areas that differ in their ability to disperse pollution in the atmosphere, the same amount of pollution emissions can have differential effects on pollution concentration. Further, this source of variation is exogenous as it is determined to a large extent by large scale weather systems.

The box model has been successfully used in a variety of air quality applications. Up until recently, both the US National Weather Service and the UK Meteorological Office used the box model for operational air quality forecasting. (See Middleton, 1998 and Munn, 1976.) Given the relatively low demand that it imposes on data, the model has also been used to compare the air pollution ventilation potential of various areas and to assess the influence of meteorology on urban pollutant concentrations, both in developed and developing countries. (See, for example, De Leeuw et al., 2002 for Europe, Vittal Murty et al., 1980 for India, and Gassmann and Mazzeo, 2000 for Argentina).

5.2 Data

Despite its routine application to many countries, to the best of our knowledge, there is no readily available data set on the distribution of ventilation coefficients worldwide. Thus, to construct

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[31] This measure is also known in the atmospheric pollution literature as the ventilation factor or air pollution potential.

[32] This result is true regardless of the size and shape of the city and the distribution of emissions within the city. More generally, the concentration of pollutants is decreasing in the ventilation coefficient for a large variety of models.

this data, we source the necessary data on meteorological outcomes - wind and mixing height - from the European Centre for Medium-Term Weather Forecasting (ECMWF) ERA-Interim data set. This data set is the latest iteration of the ECMWF's long-standing "meteorological reanalysis" efforts, whereby historical observational data is combined with the ECMWF's global meteorological forecasting model to produce a set of high quality, daily, weather outcomes on a global grid of 0.75×0.75 cells, or roughly 83 squared kilometers. Importantly for our purposes here, is the fact that the ERA-Interim source data relies overwhelmingly on satellite observations (Dee et al 2011), thus ensuring global coverage of comparable quality across locations and time.[33],[34]

Thus, to construct our measure the ventilation factor we obtain, for each of the ERA-Interim cells, monthly, 12 p.m. means of wind speed at 10 meters and mixing height[35] and multiply them to obtain a monthly ventilation coefficient. Since our focus is on long term meteorological characteristics that influence average pollution concentration for a given amount of emissions we have averaged the monthly ventilation coefficient over the period spanning January 1980 to December 2010.[36],[37] Figure 1 below maps the log of the resulting average ventilation coefficient.

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[33] As Dee et al (2011) detail these satellite observations are supplemented with data from other sources, specifically: radiosondes, pilot balloons, aircrafts, wind profilers as well as ships, drifting buoys and land weather stations' measurements.

[34] Kudamatsu et al (2011) use a previous vintage of this dataset - ERA 40 - to look at the impact of weather fluctuations on infant mortality in Africa.

[35] ERA-interim refers to mixing height as "boundary layer height"

[36] To check for the stability of our measure over this period we have also computed decade averages. The correlation of our measure across decades is close to one.

[37] As an alternative we have also considered taking averages over the worst monthly realizations in each year. The correlation with our baseline measure is high and all results below go through.

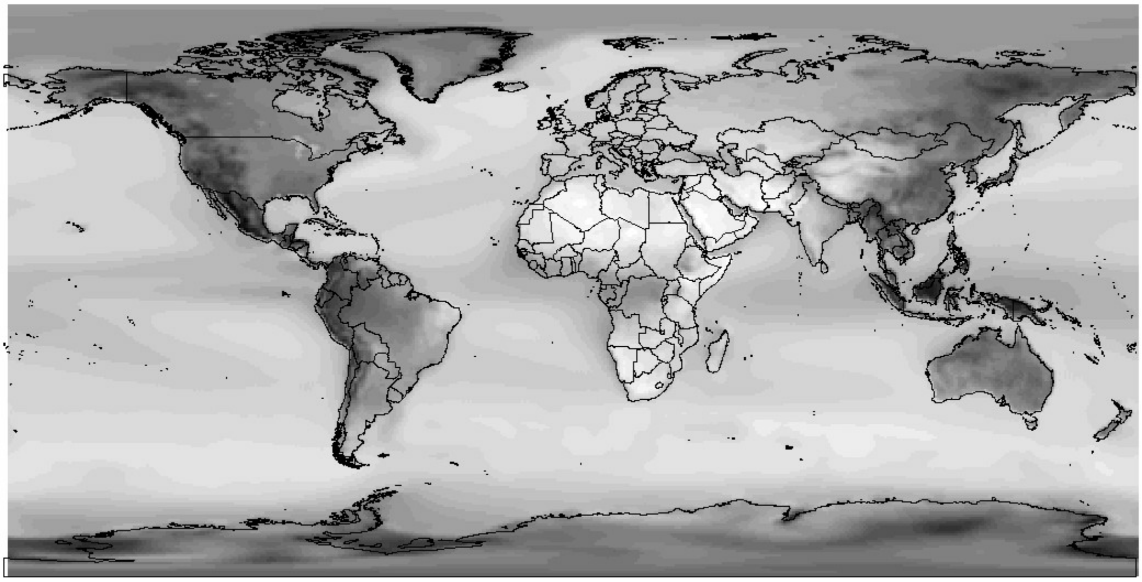

Figure 1: Log of Average Monthly Ventilation Coefficient. For each month between January 1980 and December 2010, we obtain average wind speed at 10 meters and mixing height (both at 12 p.m.) from the ERA-Interim, full resolution, dataset made available by the ECMWF. For each of the $0.75' \times 0.75'$ cells we then average over all months and take logs. Darker (lighter) areas correspond to lower (higher) ventilation coefficients.

The resulting global patterns of ventilation coefficients are in line with what is expected from the climatology literature on the global distribution of mixing height and wind speeds (see von Engeln and Teixeira, 2010, for mixing depth and Archer and Jacobson, 2005, Lu, McElroy and Kiviluoma, 2009, for wind speed). Thus, ventilation coefficients tend to be lower where both the depth of the mixing layer and wind shear are low, namely in the west coast of the American continent and South-East Asia. Conversely, in dry subtropical land regions, and in particular, in desert areas, mixing height tends to be high and wind speeds above average. Therefore ventilation coefficients tend to be high. This is the case of most of North Africa and South-West Asia as well as the southern tip of the Africa. Most of Europe, West Africa (along the Equator) and the Atlantic coast of South America display intermediate ventilation coefficients.

Given the high spatial resolution of ERA-Interim, the ventilation coefficient data described above is typically defined at the sub-national level. Instead, we are interested in exploiting cross-country variation in this measure and hence some form of aggregation to the national level is needed. Given our focus on manufacturing industries - which tend to localize in urban areas - and our usage of the Box model - geared towards the study of urban pollution - we extract information on the ventilation coefficient of each country's capital city.[38] To do this, we select the grid-cell that is nearest to the capital city and assign to the latter the average ventilation coefficient of the former.[39] We then take the ventilation coefficient of a country to be given by that of its capital. Figure 2 below presents the resulting country map. Given the high spatial correlation of our source measure across grid-cells it is not surprising that the cross-country distribution of ventilation coefficients obtained in this fashion largely mirrors the one discussed above.[40]

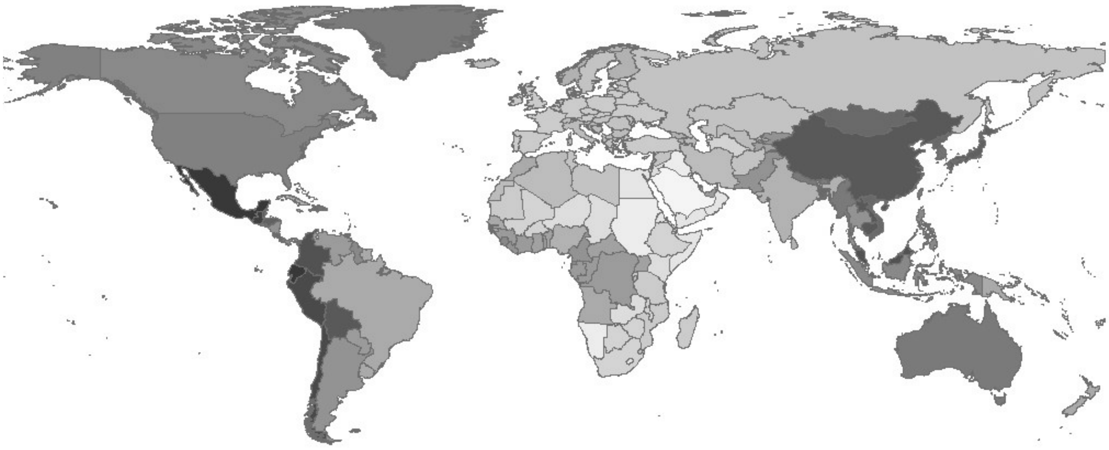

Figure 2: Log of Average Monthly Ventilation Coefficient in each country's capital. For each month between January 1980 and December 2010, we obtain average wind speed at 10 meters and mixing height (both at 12 p.m.) from the ERA-Interim, full resolution, dataset made available by the ECMWF. For each of the $0.75' \times 0.75'$ cells we compute its distance to the nearest capital city. The ventilation coefficient in each capital is then given by the value of the nearest cell. As before we average over all months and take logs. Darker (lighter) areas correspond to lower (higher) ventilation coefficients in a country's capital

Finally, and looking ahead to the next section, it is important to assess whether our ventilation coefficient measure correlates with other traditional country-level determinants of comparative advantage such as capital or skill abundance. We find that in our sample of countries there is

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[38] As an alternative we have considered taking the ventilation coefficient corresponding to the largest city in each country. The correlation between the largest city and the capital city measure is high and all of our results below are robust to considering this alternative measure. We prefer to use the capital city ventilation coefficient as our baseline measure since, for historical reasons, the location of a country's capital is unlikely to reflect concerns on whether its atmospheric conditions lead to more or less pollution dispersion.

[39] We compute this distance based on the coordinates at the center of each grid-cell in the ERA-Interim dataset and the coordinates of the capital city for each country.

[40] For that reason, if we take as an alternative country measure the simple average over the ventilation coefficients of all cells corresponding to each country we obtain a very similar distribution. The cross-country correlation between this alternative measure and our baseline, capital city, measure is 0.88 and significant at the 1% level.

no significant correlation: the correlation with capital abundance, skill abundance and GDP per capita is, respectively -0.03, -0.01 and -0.005. Further, none of these correlations are statistically significant at the 10% level. Further, our measure is only weakly correlated with oil reserves per capita (0.14, p-value of 0.09) and fertile land per capita (-0.15, p-value of 0.07).

6 Instrumental Variables

6.1 Reduced Form Results

In this section we study the effects of clean air endowments on comparative advantage in polluting industries. Thus, we analyze the direct effect of the ventilation coefficient on exports in polluting industries. As argued above, as clean air is a public good, country-level endowments affect comparative advantage in polluting goods only through their influence in environmental regulation. Thus, in the following section we use the ventilation coefficient as an instrument for environmental regulation. In this section we perform a simpler exercise: we estimate reduced form effect of clean air endowments on comparative advantage in polluting industries. This estimate is interesting in its own right because it is independent from the particular measure of air pollution regulation used and from the argument that clean air endowments only affects comparative advantage only through regulation. We thus estimate the following specification:

$$M_{ic} = \gamma_1 \; V_c \times z_i + \gamma_2 \; Y_c \times z_i + \gamma_3 \; O_c \times o_i + \gamma_4 \; K_c \times k_i + \gamma_5 \; H_c \times h_i + \alpha_c + \alpha_i + \varepsilon_{ic}, \qquad (13)$$

where V_c is the ventilation coefficient in the capital of country c, Y_c is GDP per capita, O_c is oil reserves per capita and o_i is oil intensity for industry i. Estimation results are reported in Table 8. Column 1 estimates γ_1 without including any control, and the remaining columns add controls sequentially. The first important result is that the effect of the ventilation coefficient on comparative advantage in polluting industries (γ_1) is always positive, stable across specifications and significant at 1%. The main concern to interpret the estimates of γ_1 as the effect of the clean air endowment on comparative advantage in polluting industries is that the ventilation coefficient in the capital is determined by geographical and weather characteristics that could in principle also influence a country´s level of development and thus its comparative advantage. In this case, γ_1 could be capturing the effect of a country´s level of development on exports of polluting goods instead of the effect of the clean air endowment. The results reported in columns 1 and 2 indicate that this is not the case: the estimated γ_1 is virtually unaffected by the inclusion of a control for the interaction of GDP per capita and pollution intensity, suggesting that γ_1 is indeed capturing the effect of the clean air endowment on comparative advantage. The inclusion of controls for the oil, skill and capital interactions also have minor effects on the estimated γ_1. The estimated coefficient on the on the ventilation and pollution interaction ($V_c \times z_i$) reported in column 5 implies that if a country moves from the mean to a one standard deviation below the mean in air pollution regulation, the predicted relative import share of an industry that is one standard deviation above the mean pollution intensity increases by 4.5% of a standard deviation.

6.2 Instrumental Variable Strategy

Can we interpret the OLS results presented in Section 4 as the causal effect of environmental regulation on comparative advantage? As discussed above, an alternative interpretation is that comparative advantage in polluting industries influences environmental regulation. This reverse causality channel could upwards bias the estimated effect of environmental regulation if a country with a comparative advantage in polluting industries faces a stronger industry lobby to enact lax environmental regulations. On the contrary, our estimates could be downwards biased if a comparative advantage in polluting industries results in higher levels of pollution, which induce the population to demand clean air regulations. To address this concern we need an instrument for environmental regulation. That is, a source of variation in environmental regulation that is not determined by comparative advantage in polluting industries (exogenous) and does not affect comparative advantage through other channels (exclusion restriction). As discussed above, the ventilation coefficient is exogenous because it is determined by invariant weather and geographical characteristics. It also arguably satisfies the exclusion restriction. The main concern on this respect is that these geographical and weather characteristics could also influence a country´s level of development or endowments of other production factors and thus shape its comparative advantage through these other channels. The simple correlations in the data reported above suggest that this is not the case: the correlation coefficient of the ventilation coefficient and GDP per capita, capital and skill endowments are between -0.005 and 0.03 and not statistically different from zero. The almost zero correlation between the ventilation coefficient and other determinants of comparative advantage suggest that the exclusion restriction is satisfied. Still, we include them as controls in what follows.

Our instrumental variable estimation strategy follows the following steps. In the first stage we estimate the following equation:

$$E_c \times z_i = \delta_1 \ V_c \times z_i + \delta_2 Y_c \times z_i + \delta_3 \ K_c \times k_i + \delta_4 \ H_c \times h_i + \theta_c + \theta_i + \nu_{ic}, \tag{14}$$

where the dependent variable is the interaction of environmental regulation in country c and pollution intensity in industry i ($E_c \times z_i$) and our excluded instrument is the interaction of the ventilation coefficient in country c and pollution intensity in industry i ($V_c \times z_i$). In the second stage we estimate the following equation:

$$M_{ic} = \beta_1 \ \widehat{E_c \times z_i} + \beta_2 Y_c \times z_i + \beta_3 \ K_c \times k_i + \beta_4 \ H_c \times h_i + \alpha_c + \alpha_i + \varepsilon_{ic} \tag{15}$$

where $\widehat{E_c \times z_i} = \widehat{\delta}_1 \ V_c \times z_i + \widehat{\delta}_2 Y_c \times z_i + \widehat{\delta}_3 \ K_c \times k_i + \widehat{\delta}_4 \ H_c \times h_i + \widehat{\theta}_c + \widehat{\theta}_i$ and $\widehat{\delta}, \widehat{\theta}$ are coefficient estimates of equation 14.

6.2.1 First Stage Results

Note that the only term of the pollution interaction that we instrument is environmental regulation (E_c), not pollution intensity (z_i) as it is measured using lagged U.S. industry characteristics thus it is arguably exogenous to a particular country´s exports. Thus, before turning to the discussion of the first stage results, we report the effect of the ventilation box coefficient on country-level environmental regulation. Table 9 reports coefficient estimates of a regression of lax environmental regulation (E_c) on the ventilation coefficient (V_c). The estimated coefficient reported in column 1 indicates that a one standard deviation increase in the ventilation coefficient induces a 22% of a standard deviation decrease in the stringency of environmental regulation. Subsequent columns show that this estimate is robust to the inclusion of other country characteristics like per capita GDP, fertile land per capita, oil reserves per capita, capital and skill endowments and the efficiency of legal institutions. Note in particular that the inclusion for a control for GDP per capita in column 2 does not significantly affect the estimated effect of the ventilation coefficient on environmental regulation. This evidence supports the exclusion restriction: the ventilation coefficient has a direct effect on environmental regulation and is not capturing the effect of geographical or weather characteristics on the level of income. This is crucial because income per capita can affect the demand for environmental regulation and shape comparative advantage. Similarly, the stability of the coefficient when controls for other country characteristics are included suggests that the exclusion restriction is satisfied. The relationship between environmental regulation (E_c) on the ventilation coefficient (V_c) is illustrated in Figure 3, where country names are included. Fitted values correspond to the regression reported in column 2, where GDP per capita is included as a control.

Next, we turn to the estimation of the first stage regression described in equation 14, reported in Table 10. The first column includes only the interaction of the ventilation coefficient and pollution intensity ($V_c \times z_i$) and the rest of the columns add the remaining controls sequentially. The estimated coefficient on $V_c \times z_i$ is positive, stable and statistically significant at 1% in all specifications. The F-test on the excluded instrument ($V_c \times z_i$) varies between a value of 152 in column 1 where no controls are included and 125.56 in the last column where all controls are included.

6.2.2 Second Stage Results

Panel A in Table 11 reports estimation of the second stage regression described in equation 15. The first column includes only the (instrumented) interaction between environmental regulation and pollution intensity ($\widehat{E_c \times z_i}$) and the rest of the columns add the remaining controls sequentially. The estimated coefficient on $\widehat{E_c \times z_i}$ (β_1) is positive, stable and statistically significant at 1% in all specifications. The stability of the estimated coefficient when controls for other country characteristics are included suggests that the exclusion restriction is satisfied: the ventilation coefficient affects comparative advantage through its effect on environmental regulation, not because it is correlated with other sources of comparative advantage. The estimated coefficient on the pollution interaction ($E_c \times z_i$) reported in column 3, where controls for the capital and skill interactions are included, implies that if a country moves from the mean to a one standard deviation below the mean in air pollution regulation, the predicted relative import share of an industry that is one standard deviation above the mean pollution intensity increases by 18,6% of a standard deviation.

Panel B in Table 11 reports OLS estimation of an equation equivalent to 15. The OLS baseline estimate of β_1 is 10,8%, as reported in column 3. Then, our baseline instrumental variable estimates of the effect of environmental regulation on comparative advantage in polluting industries are around 80% higher than OLS estimates. This finding has two possible interpretations. First, OLS estimates could be biased if comparative advantage in polluting industries influences environmental regulation. Second, our measure of environmental regulation is at best partial, thus OLS estimates might be downward biased due to measurement error. The first interpretation is related to our discussion of reverse causality at the beginning if this section. Reverse causality could upwards bias the estimated effect of environmental regulation if a country with a comparative advantage in polluting industries faces a stronger industry lobby to enact lax environmental regulations. On the contrary, our estimates could be downwards biased if a comparative advantage in polluting industries results in higher levels of pollution, which induce the population to demand clean air regulations. Our instrumental variables results suggest that this second channel could be operative. In particular, some advanced countries that industrialized earlier might have faced stronger demand from their citizens to address air pollution problems. Thus, if these countries tend to export more in polluting industries but also have more stringent environmental regulation OLS estimates of

β_1 can be downwards biased. The second interpretation is highly plausible, as our measure of environmental regulation only captures one dimension of air pollution regulation that is easily comparable across countries, thus it is subject to measurement error. Thus, the results suggest that our instrument captures the variation in the environmental regulation measure that is directly driven by the broader effect of meteorological conditions on the demand for cleaner air and air pollution policy.

7 Final Remarks

TO BE WRITTEN

References

[1] Abt Associates Inc., (2009). "Trade and Environmental Assessment Model: Model Description," prepared for the U.S. Environmental Protection Agency National Center for Environmental Economics/Climate Economics Branch, Cambridge MA: Abt Associates.

[2] Antras, P., (2003). "Firms, Contracts, and Trade Structure," *Quarterly Journal of Economics* 118, 1375-418.

[3] Antweiler, W., B. Copeland, and S. Taylor, (2001). "Is Free Trade Good for the Environment?" *American Economic Review* 91, 877-908.

[4] Archer, C., and M. Jacobson, (2005). "Evaluation of Global Wind Power," *Journal of Geophysical Research - Atmospheres* 110, D12110.

[5] Associated Octel, (1996). "Worldwide Gasoline and Diesel Fuel Survey," London: Associated Octel Ltd.

[6] Beck, T., (2003). "Financial Dependence and International Trade," *Review of International Economics* 11, 296-316.

[7] Becker, R., and J. Henderson, (2000). "Effects of Air Quality Regulations on Polluting Industries," *Journal of Political Economy* 108, 379-421.

[8] Besley, T., and T. Persson, (forthcoming). "The Origins of State Capacity: Property Rights, Taxation and Politics," *American Economic Review.*

[9] Brunnermeier, S., and A. Levinson, (2004). "Examining the Evidence on Environmental Regulations and Industry Location," *Journal of the Environment and Development* 13, 6-41.

[10] Chichilnisky, G., (1994). "North-South Trade and the Global Environment," *American Economic Review* 84, 851-74.

[11] Chor, D., (2010). "Unpacking Sources of Comparative Advantage: A Quantitative Approach," *Journal of International Economics* 82, 152-67.

[12] Cole, M., R. Elliott, and P. Fredriksson, (2006). "Endogenous Pollution Havens: Does FDI Influence Environmental Regulations?" *Scandinavian Journal of Economics* 108, 157-78.

[13] Cole M., R. Elliott, and K. Shimamoto, (2005). "Industrial Characteristics, Environmental Regulations and Air Pollution: An Analysis of the U.K. Manufacturing Sector," *Journal of Environmental Economics and Management* 50, 121-43.

[14] Copeland, B., (1994). "International Trade and the Environment: Policy Reform in a Polluted Small Open Economy," *Journal of Environmental Economics and Management* 26, 44-65.

[15] Copeland, B., and M. Taylor, (1994). "North-South Trade and the Environment," *Quarterly Journal of Economics* 109, 755-87.

[16] Copeland, B., and M. Taylor, (1995). "Trade and Transboundary Pollution," *American Economic Review* 85, 716-37.

[17] Copeland, B., and M. Taylor, (2003). *Trade and the Environment: Theory and Evidence*, Princeton University Press.

[18] Copeland, B., and M. Taylor, (2004). "Trade, Growth, and the Environment," *Journal of Economic Literature* 42, 7-71.

[19] Costinot, A., (2009). "On the Origins of Comparative Advantage," *Journal of International Economics* 77, 255-64.

[20] Cuñat, A., and M. Melitz, (forthcoming). "Volatility, Labor Market Flexibility, and the Pattern of Comparative Advantage," *Journal of the European Economic Association.*

[21] Damania, R., P. Fredriksson, and J. List, (2003). "Trade Liberalization, Corruption, and Environmental Policy Formation: Theory and Evidence," *Journal of Environmental Economics and Management* 46, 490-512.

[22] Dasgupta, S., A. Mody, D. Roy, and D. Wheeler, (2001). "Environmental Regulation and Development: A Cross-country Empirical Analysis," *Oxford Development Studies*, Taylor and Francis Journals, 29, 173-87.

[23] De Leeuw, F., E. van Zantvoort, R. Sluyter, and W. van Pul, (2002). "Urban Air Quality Assessment Model: UAQAM," *Environmental Modeling & Assessment* 7, 243-58.

[24] Dee, D.P. et al (2011), The ERA-Interim Reanalysis: Configuration and Performance of the Data Assimilation System, Quarterly Journal of the Royal Meteorological Society, 137, pp. 553-597, April.

[25] Eaton, J., and S. Kortum, (2002). "Technology, Geography, and Trade," *Econometrica* 70, 1741-79.

[26] Ederington, J., A. Levinson, and J. Minier, (2005). "Footloose and Pollution-free," *Review of Economics and Statistics* 87, 92-9.

[27] Ederington, J., and J. Minier, (2003). "Is Environmental Policy a Secondary Trade Barrier? An Empirical Analysis," *Canadian Journal of Economics* 36, 137-54.

[28] Environmental Protection Agency (2005), Basic Air Pollution Meteorology, E.P.A., Air Pollution Training Institute. Research Triangle Park, NC.

[29] Environmental Protection Agency (2004), Risk Assessment and Modeling - Air Toxics Risk Assessment, Volume 1 - Technical Resource Manual. E.P.A., Office of Air Quality Planning and Standards, Emissions Standards Division, Research Triangle Park, NC.

[30] Esty, D., M. Levy, T. Srebotnjak, and A. Sherbinin, (2005). *2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship*. New Haven: Yale Center for Environmental Law & Policy.

[31] Feenstra, R., J. Romalis, and P. Schott, (2002). "U.S. Imports, Exports and Tariff Data, 1989-2001," *NBER Working Paper* 9387.

[32] Greenstone, M., (2002). "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Acts and the Census of Manufactures," *Journal of Political Economy* 110, 1175-219.

[33] Grossman, G., and A. Krueger, (1993). "Environmental Impacts of a North American Free Trade Agreement," in The U.S.-Mexico Free Trade Agreement, P. Garber ed., MIT Press, 13-56.

[34] Grossman, G., and A. Krueger, (1995). “Economic Growth and the Environment,” *Quarterly Journal of Economics* 110, 353-77.

[35] Hall, R., and C. Jones, (1999). “Why Do Some Countries Produce So Much More Output per Worker than Others?” *Quarterly Journal of Economics*, 14, 83-116.

[36] Hettige, H., P. Martin, M. Singh, and D. Wheeler (1995). “The Industrial Pollution Projection System,” *World Bank Policy Research Working Paper* 1431.

[37] Hilton, F. G. H. and Levinson, A. M., 1998. Factoring the environmental Kuznets curve: evidence from automotive lead emissions, *Journal of Environmental Economics and Management*, 35: 126-41.

[38] Jacobson, Marc Z. (2002), Atmospheric Pollution. History, Science and Regulation, Cambridge University Press

[39] Middleton, D.R. (1998), A New Box Model to Forecast Urban Air Quality: BOXURB, Environmental Monitoring and Assessment, Vol 52, 1-2, pp 315-335.

[40] Munn, R.E. (1976), Air Pollution Metereology, in Urban Air Quality Management, M.J. Suess and S.R. Craxford (eds.), WHO Regional Publications, European Series N. 1, World Health Organization, Copenhagen.

[41] Jaffe, A., S. Peterson, P. Portney, and R. Stavins, (1995). “Environmental Regulations and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?” *Journal of Economic Literature* 33, 132-63.

[42] Keller, W., and A. Levinson, (2002). “Pollution Abatement Costs and Foreign Direct Investment Inflows to U.S. States,” *Review of Economics and Statistics* 84, 691-703.

[43] Kudamatsu, M., T. Persson and D. Stromber (2011), Weather and Infant Mortality in Africa", mimeo IIES, Stockholm University.

[44] Leontief, W., (1970) “Environmental Repercussions and the Economic Structure: An Input-Output Approach.” *Review of Economics and Statistics*, 52(3): 262–71.

[45] Levchenko, A., (2007). “Institutional Quality and International Trade,” *Review of Economic Studies* 74, 791-819.

[46] Levinson, A., (2009). “Technology, International Trade, and Pollution from U.S. Manufacturing,” *American Economic Review* 99, 2177-92.

[47] Levinson, A., and S. Taylor, (2008). "Unmasking the Pollution Haven Effect," *International Economic Review* 49, 223-54.

[48] List, J., D. Millimet, P. Fredriksson, and W. McHone, (2003). "Effects of Environmental Regulations on Manufacturing Plant Births: Evidence From a Propensity Score Matching Estimator," *Review of Economics and Statistics* 85, 944-52.

[49] List, J., and D. Sturm, (2006). "How Elections Matter: Theory and Evidence from Environmental Policy," *Quarterly Journal of Economics* 121, 1249-81.

[50] Lovei, M., (1998). "Phasing Out Lead From Gasoline, Worlwide Experience and Policy Implications," *World Bank Technical Paper* 397, Pollution Management Series.

[51] Lu, X. M.B. McElroy and J. Kiviluoma (2009), Global Potential for Wind-Generated Electricity, Proceedings of the National Academies of Sciences, vol 106, n. 27, pp. 10933-10938.

[52] Lu, Z., D. G. Streets, Q. Zhang, S. Wang, G. R. Carmichael, Y. F. Cheng, C. Wei, M. Chin, T. Diehl, and Q. Tan, (2010). "Sulfur Dioxide Emissions in China and Sulfur Trends in East Asia," *Atmospheric Chemistry and Physics* 10, 6311-31.

[53] Mani, M., and D. Wheeler, (1999). "In Search of Pollution Havens? Dirty Industry Migration in the World Economy," in *Trade, Global Policy and the Environment*, P. Frederiksson ed., *World Bank Discussion Paper* 402.

[54] Manova, K., (2008). "Credit Constraints, Heterogeneous Firms, and International Trade," *NBER Working Paper* 14531.

[55] McGuire, M., (1982). "Regulation, Factor Rewards, and International Trade," *Journal of Public Economics* 17: 335-54.

[56] Nunn, N., (2007). "Relationship-Specificity, Incomplete Contracts and the Pattern of Trade," *Quarterly Journal of Economics* 122, 569-600.

[57] Pethig, R., (1976). "Pollution, Welfare, and Environmental Policy in the Theory of Comparative Advantage," *Journal of Environmental Economics and Management* 2, 160-9.

[58] Rauscher, M., (1997). *International Trade, Factor Movements, and the Environment.* Oxford University Press.

[59] Romalis, J., (2004). "Factor Proportions and the Structure of Commodity Trade," *American Economic Review* 94, 67-97.

[60] Vittal Murty, K. P. R., D. V. Viswanadham, Y. Sadhuram. (1980) Mixing heights and ventilation coefficients for urban centres in India. Boundary-Layer Meteorology 19:4, 441-451.

[61] Von Engeln, A. and J. Teixeira (2010), A Planetary Boundary Layer Height Climatology derived from ECMWF Re-analysis Data, mimeo. Satellite Atmospheric Science Group, Lulea University of Technology.

[62] World Bank, (2004). *Doing Business in 2004: Understanding Regulation*, World Bank and Oxford University Press.

[63] World Economic Forum, (2004). *The Global Competitiveness Report 2003-2004*, M. Porter, K. Schwab, X. Sala-i-Martin, and A. Lopez-Claro eds., Oxford University Press.

8 Appendix 1 Proof of Result 2

Taking the derivative of Equation (8) with respect to A_j and rearranging we obtain

$$\frac{d\bar{Z}_j^*}{dA_j} = P_d \cdot A_j^{\gamma-1} \cdot \frac{I_j\left(\bar{Z}_j^*\right) \cdot U''\left(I_j\left(\bar{Z}_j^*\right)\right) + \gamma \cdot U'\left(I_j\left(\bar{Z}_j^*\right)\right)}{\phi_j^2 \cdot V''\left(\phi_j \cdot \bar{Z}_j^*\right) - P_d^2 \cdot A_j^{2\cdot\gamma} \cdot U''\left(I_j\left(\bar{Z}_j^*\right)\right)}.$$

The denominator is positive because $V'' > 0$ and $U'' < 0$. If $\gamma = 0$, the numerator is negative because $U'' < 0$ and the second term disappears. This proves the first result. Otherwise, since $\gamma < 1$ and $U' > 0$, the numerator is smaller than

$$I_j\left(\bar{Z}_j^*\right) \cdot U''\left(I_j\left(\bar{Z}_j^*\right)\right) + U'\left(I_j\left(\bar{Z}_j^*\right)\right),$$

which is negative if $-c \cdot U''(c)/U'(c) > 1$. This proves the second result.

9 Appendix 2: The Box model

The model determines the concentration of pollutants within the box $\{(x, y, z) : x \in [0, L], y \in [0, L], z \in [0, h]\}$. The concentration of pollutants does not depend on height z since vertical dispersion is instantaneous. Thus, let $\rho(x, y, t)$ denote pollution at (x, y, z) at time t for all $z \in [0, h]$. Wind blows in the ascending y direction.

Consider the sub-box $\{(x', y', z') : x' \in [0, x], y' \in [0, y], z' \in [0, h]\}$. The change in total pollution within the sub-box is given by

$$\frac{d}{dt} \int_0^x \int_0^y \rho\left(x', y', t\right) \cdot h \cdot dy' \cdot dx' = x \cdot y \cdot Q - \int_0^x \rho\left(x', y, t\right) \cdot u \cdot h \cdot dx', \tag{16}$$

where h is mixing height, u is wind speed, and Q is emissions per unit area. The first term on the right hand side is the pollution emmitted within the sub-box and the second term is the pollution that leaves the sub-box. The latter depends on the concentration of pollution at the downwind side and the speed at which dirty air leaves the sub-box.

In steady state, the total pollution within the sub-box is constant and, thus, we have

$$\int_0^x \rho\left(x', y\right) \cdot dx' = x \cdot y \cdot \frac{Q}{u \cdot h}, \tag{17}$$

where we have ommited the time dependence. Taking the derivative of Equation (17) with respect to x we find

$$\rho\left(x, y\right) = y \cdot \frac{Q}{u \cdot h}. \tag{18}$$

Note that the concentration of pollutants is not constant within the urban area. It is zero at the upwind edge of the urban area and increases linearly with distance from this edge.

The average concentration of pollution in the urban area is

$$C = \frac{1}{L^2} \cdot \int_0^L \int_0^L \rho\left(x, y\right) \cdot dy \cdot dx. \tag{19}$$

Given Equation (18), this implies

$$C = \frac{L}{2} \cdot \frac{Q}{u \cdot h}. \tag{20}$$

Table 1: Ten most pollution intensive manufacturing industries for each pollutant.

Emission Factors are in Tons per million of dollars shipped.

	NOx			S02			CO		
Rank	Industry	EF	%Total	Industry	EF	%Total	Industry	EF	%Total
1	Lime and gypsum	6.68	1	Pulp/paper/paperboard mills	5.17	14	Alumina and aluminum	14.2	7
2	Cement and concrete	5.42	10	Lime and gypsum	4.85	1	Iron/Steel Mills and Ferroalloy	7.94	7
3	Glass and glass products	3.8	3	Nonferrous Metal(not Aluminum)	4.67	4	Lime and Gypsum	7.08	1
4	Pulp/paper/paperboard mills	3.67	10	Cement and concrete	4.22	7	Pulp/paper/paperboard mills	5.56	7
5	Pesticide & fertilizer	2.22	2	Alumina and Aluminum	4.19	4	Other Nonmetallic Mineral	4.81	1
6	Basic Chemicals	1.96	8	Pesticide & fertilizer	3.18	2	Steel Products	4.62	1
7	Petroleum and Coal Products	1.42	12	Basic Chemicals	2.69	11	Cement and Concrete	4.44	3
8	Veneer/Plywood/Eng. Wood	1.19	1	Petroleum and Coal Products	2.30	18	Basic Chemicals	4.36	8
9	Iron/Steel Mills and Ferroalloy	1.14	2	Other Chemical Products	1.89	3	Veneer/Plywood/Eng.Wood	3.29	1
10	Clay Product and Refractory	1.08	1	Veneer/Plywood/Eng. Wood	1.72	3	Nonferrous Metal(not Alum.)	3.24	1
% of Total Accounted by top 10			50	% of Total Accounted by top 10		66	% of Total Accounted by top 10		38

Emission Factors are in Tons per million of dollars shipped. "% Total" gives the industry's share of total emissions in manufacturing.

Table 2: Rank correlation of pollution intensity ranking of industries.

	NOx	SO2	CO
NOx	1	-	-
SO2	0.58***	1	-
CO	0.90***	0.44***	1

*** indicates significance at the 1 percent level.

Table 3: Correlation between Pollution, Skill and Capital Intensities.

	NOx	SO2	CO
	1	-	-
Skill Intensity	-0.24**	-0.19*	-0.25**
Capital Intensity	0.33***	0.52***	0.53***

* indicates significance at the 10 percent level,** indicates significance at the 5 percent level, *** at 1 per cent level.

Table 4: Grams of Lead per Liter of Gasoline: the ten least and ten most stringent countries

Rank	Most Stringent Regulation	Value	Least Stringent Regulation	Value
1	Sweden	0	Venezuela	0.85
2	Denmark	0	Burkina Faso	0.84
3	Finland	0	Burundi	0.84
4	Japan	0	Cameroon	0.84
5	Canada	0	Chad	0.84
6	Austria	0	Cuba	0.84
7	Bolivia	0	Lebanon	0.84
8	Guatemala	0	Uganda	0.84
9	Brazil	0	Zimbabwe	0.84
10	Thailand	0	Benin	0.84

Median is 0.38, mean is 0.36. South Africa is the country closes to the global mean.

Source: Lovei (1998)

Table 5
Environmental Regulation and Comparative Advantage in Polluting Goods

Dependent Variable: Import Share

	1	2	3	4
Lax Air Pollution Regulation $_c$ × Pollution Intensity $_i$	0.0624*** (0.0126)			
Lax Air Pollution Regulation $_c$ × NOx Intensity $_i$		0.0539*** (0.0123)		
Lax Air Pollution Regulation $_c$ × SO2 Intensity $_i$			0.0615*** (0.0128)	
Lax Air Pollution Regulation $_c$ × CO Intensity				0.0621*** (0.0121)
Country fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	8,585	8,585	8,585	8,585

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6
Environmental Regulation and Comparative Advantage in Polluting Goods –Baseline OLS Results

Dependent Variable: Import Share

	1	2	3	4	5	6	7	8
Lax Air Pollution Regulation $_c$ × Pollution Intensity $_i$	0.0780***	0.0832***	0.0834***	0.0793***	0.0789***	0.0881***	0.0804***	0.0704***
	(0.0153)	(0.0175)	(0.0175)	(0.0178)	(0.0170)	(0.0186)	(0.0181)	(0.0180)
Skill Abundance $_c$ × Skill Intensity $_i$		0.0660***	0.0683***	0.0624***	0.0659***	0.0667***	0.0628***	0.0570***
		(0.0121)	(0.0122)	(0.0123)	(0.0121)	(0.0126)	(0.0126)	(0.0128)
Capital Abundance $_c$ × Capital Intensity $_i$		0.0515***	0.0531***	0.0596***	0.0478***	0.0542***	0.0580***	0.0680***
		(0.0145)	(0.0147)	(0.0140)	(0.0142)	(0.0150)	(0.0151)	(0.0146)
Income per capita $_c$ × TFP growth $_i$			-0.00897					
			(0.0141)					
Income per capita $_c$ × VA $_i$				0.0243				0.0407**
				(0.0163)				(0.0172)
Oil Abundance $_c$ × Oil Intensity $_i$					0.0870***			0.0886***
					(0.00664)			(0.00729)
Efficiency of Legal Institutions $_c$ × Contract Intensity $_i$							0.0429***	0.0402***
							(0.0154)	(0.0150)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,205	6,205	6,205	6,205	6,205	5,780	5,780	5,780

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7
Environmental Regulation and Comparative Advantage in Polluting Goods –Robustness OLS Results

Dependent Variable: Import Share

	1	2	3	4	5	6	7	8
Lax Air Pollution Regulation $_c$ × Pollution Intensity $_i$	0.0624***	0.0971***	0.0601***	0.102***	0.122***	0.0741***	0.0665***	0.104***
	(0.0126)	(0.0184)	(0.0126)	(0.0192)	(0.0224)	(0.0151)	(0.0165)	(0.0242)
Pollution Intensity $_i$ × Income per capita $_c$		0.0553***						-0.0890
		(0.0186)						(0.0644)
Pollution Intensity $_i$ × Fertile Land per capita $_c$			0.0241**					0.0240**
			(0.0118)					(0.0115)
Pollution Intensity $_i$ × Capital Abundance $_c$				0.0617***				0.0893
				(0.0185)				(0.0611)
Pollution Intensity $_i$ × Skill Abundance $_c$					0.0636***			0.0590**
					(0.0198)			(0.0298)
Pollution Intensity $_i$ × Oil Abundance $_c$						0.0396		0.0342
						(0.0284)		(0.0301)
Pollution Intensity $_i$ × Eff. Legal Institutions $_c$							-0.0370**	-0.0306*
							(0.0182)	(0.0182)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,585	8,585	8,585	8,585	6,205	6,205	5,780	5,780

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8

Ventilation Potential and Comparative Advantage in Polluting Goods –Reduced Form Results

Dependent Variable: Import Share

	1	2	3	4	5	6	7
Ventilation Potential $_c$ × Pollution Intensity $_i$	0.0569***	0.0570***	0.0545***	0.0454***	0.0450***	0.0455***	0.0408***
	(0.00978)	(0.00977)	(0.00949)	(0.0119)	(0.0119)	(0.0119)	(0.0113)
Pollution Intensity $_i$ × Income per capita $_c$		0.0167*	0.0128			-0.0148	-0.0184
		(0.00995)	(0.00970)			(0.0139)	(0.0136)
Oil Abundance $_c$ × Oil Intensity $_i$			0.0566***				0.0792***
			(0.0204)				(0.00698)
Skill Abundance $_c$ × Skill Intensity $_i$					0.0578***	0.0556***	0.0545***
					(0.0108)	(0.0112)	(0.0111)
Capital Abundance $_c$ × Capital Intensity $_i$					0.0231**	0.0314***	0.0314***
					(0.0113)	(0.0121)	(0.0121)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,750	12,750	12,580	8,075	8,075	8,075	8,075

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 9
Ventilation Potential and Environmental Regulation

Dependent Variable: Lax Environmental Regulation

	1	2	3	4	5	6	7	8	9
Ventilation Potential $_c$	0.219***	0.211***	0.220***	0.218***	0.184***	0.218**	0.188**	0.217***	0.230***
	[0.0815]	[0.0690]	[0.0686]	[0.0693]	[0.0691]	[0.0841]	[0.0918]	[0.0743]	[0.0739]
Income per capita $_c$		-0.624***	-0.617***	-0.628***	-0.680***	-0.680***	-0.202	-0.659***	-0.564***
		[0.0584]	[0.0589]	[0.0582]	[0.0536]	[0.0681]	[0.305]	[0.0610]	[0.0723]
Fertile Land per capita $_c$			0.0627						
			[0.0808]						
Oil Abundance $_c$					0.216***				
					[0.0584]				
Skill Abundance $_c$							-0.351**		
							[0.153]		
Capital Abundance $_c$							-0.183		
							[0.281]		
Efficiency Legal Institutions $_c$									-0.246***
									[0.0848]
Observations	101	101	101	99	99	73	73	89	89

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 10
Ventilation Potential and Environmental Regulation- First Stage Results

Dependent Variable: Environmental Regulation $_c$ × Pollution Intensity $_i$

	1	2	3	4	5	6	7	8	9	10	11
Ventilation Potential $_c$ × Pollution Intensity $_i$	0.219***	0.211***	0.218***	0.217***	0.191***	0.186***	0.186***	0.201***	0.206***	0.203***	0.213***
	[0.0177]	[0.0149]	[0.0181]	[0.0181]	[0.0198]	[0.0218]	[0.0227]	[0.0190]	[0.0189]	[0.0189]	[0.0190]
Pollution Intensity $_i$ × Income per capita $_c$		-0.624***	-0.680***	-0.656***				-0.671***	-0.632***	-0.635***	-0.632***
		[0.0126]	[0.0147]	[0.0174]				[0.0159]	[0.0195]	[0.0194]	[0.0194]
Skill Abundance $_c$ × Skill Intensity $_i$				0.0353***	0.135***				0.0232***	0.0228***	0.0248***
				[0.00676]	[0.0112]				[0.00735]	[0.00734]	[0.00723]
Capital Abundance $_c$ × Capital Intensity $_i$				-0.0217**	-0.387***				-0.0146	-0.0145	-0.0129
				[0.0109]	[0.0161]				[0.0116]	[0.0116]	[0.0117]
Eff. of Legal Institutions $_c$ × Contract Intensity $_i$									0.0880***	0.0850***	0.0836***
									[0.0152]	[0.0151]	[0.0151]
Oil Abundance $_c$ × Oil Intensity $_i$										0.0423***	0.0424***
										[0.00705]	[0.00667]
Pollution Intensity $_i$ × Fertile Land per capita $_c$											0.0627***
											[0.0223]
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,585	8,585	6,205	6,205	6,205	6,205	5,780	5,780	5,780	5,780	5,780

Robust standard errors in brackets
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 11
Environmental Regulation and Comparative Advantage in Polluting Goods.
Panel A: Instrumental Variables Results

Dependent Variable: Import Share

	1	2	3	4	5	6	7	8	9	10	11
Lax Air Pollution Regulation $_c$ × Pollution Intensity $_i$	0.237***	0.246***	0.193***	0.186***	0.207***	0.219***	0.246***	0.231***	0.238***	0.213***	0.232***
	[0.0570]	[0.0584]	[0.0624]	[0.0628]	[0.0715]	[0.0739]	[0.0792]	[0.0720]	[0.0715]	[0.0687]	[0.0663]
Pollution Intensity $_i$ × Income per capita $_c$		0.149***	0.105**	0.100**				0.123**	0.129***	0.108**	0.122***
		[0.0386]	[0.0437]	[0.0430]				[0.0499]	[0.0482]	[0.0451]	[0.0433]
Skill Abundance $_c$ × Skill Intensity $_i$				0.0668***	0.0489***				0.0625***	0.0624***	0.0628***
				[0.0126]	[0.0154]				[0.0130]	[0.0130]	[0.0131]
Capital Abundance $_c$ × Capital Intensity $_i$				0.0350**	0.0988***				0.0443***	0.0442***	0.0451***
				[0.0142]	[0.0304]				[0.0149]	[0.0148]	[0.0148]
Eff. of Legal Institutions $_c$ × Contract Intensity $_i$									0.0349**	0.0315**	0.0292*
									[0.0153]	[0.0149]	[0.0149]
Oil Abundance $_c$ × Oil Intensity $_i$										0.0784***	0.0776***
										[0.00832]	[0.00808]
Pollution Intensity $_i$ × Fertile Land per capita $_c$											0.0254**
											[0.0125]
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,585	8,585	6,205	6,205	6,205	6,205	5,780	5,780	5,780	5,780	5,780

Robust standard errors in brackets
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 12
Environmental Regulation and Comparative Advantage in Polluting Goods.
Panel B: OLS Results

Dependent Variable: Import Share

	1	2	3	4	5	6	7	8	9	10	11
Lax Air Pollution Regulation $_c$ × Pollution Intensity $_i$	0.0624***	0.0971***	0.112***	0.108***	0.0832***	0.0780***	0.0815***	0.110***	0.101***	0.0925***	0.0910***
	[0.0124]	[0.0182]	[0.0227]	[0.0227]	[0.0172]	[0.0151]	[0.0161]	[0.0233]	[0.0228]	[0.0215]	[0.0217]
Pollution Intensity $_i$ × Income per capita $_c$		0.0553***	0.0501**	0.0497**				0.0425*	0.0438*	0.0325	0.0329
		[0.0184]	[0.0213]	[0.0228]				[0.0217]	[0.0234]	[0.0215]	[0.0215]
Skill Abundance $_c$ × Skill Intensity $_i$				0.0701***	0.0660***				0.0664***	0.0658***	0.0669***
				[0.0122]	[0.0119]				[0.0127]	[0.0127]	[0.0128]
Capital Abundance $_c$ × Capital Intensity $_i$				0.0331**	0.0515***				0.0416***	0.0418***	0.0424***
				[0.0140]	[0.0143]				[0.0147]	[0.0147]	[0.0147]
Efficiency of Legal Institutions $_c$ × Contract Intensity $_i$									0.0452***	0.0400***	0.0391***
									[0.0153]	[0.0147]	[0.0147]
Oil Abundance $_c$ × Oil Intensity $_i$										0.0851***	0.0856***
										[0.00699]	[0.00689]
Pollution Intensity $_i$ × Fertile Land per capita $_c$											0.0295***
											[0.0112]
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,585	8,585	6,205	6,205	6,205	6,205	5,780	5,780	5,780	5,780	5,780

Robust standard errors in brackets

*** $p<0.01$, ** $p<0.05$, * $p<0.1$