DISCUSSION PAPER SERIES

No. 9111

SOURCES OF COMPARATIVE ADVANTAGE IN POLLUTING INDUSTRIES

Fernando A Broner, Paula Bustos and
Vasco M Carvalho

DEVELOPMENT ECONOMICS,
INTERNATIONAL MACROECONOMICS,
INTERNATIONAL TRADE AND REGIONAL
ECONOMICS and PUBLIC POLICY

Centre for Economic Policy Research

www.cepr.org

ISSN 0265-8003

SOURCES OF COMPARATIVE ADVANTAGE IN POLLUTING INDUSTRIES

Fernando A Broner, CREI, Universitat Pompeu Fabra and CEPR
Paula Bustos, CREI and Universitat Pompeu Fabra and CEPR
Vasco M Carvalho, CREI, Universitat Pompeu Fabra and CEPR

Discussion Paper No. 9111
September 2012

Centre for Economic Policy Research
77 Bastwick Street, London EC1V 3PZ, UK
Tel: (44 20) 7183 8801, Fax: (44 20) 7183 8820
Email: cepr@cepr.org, Website: www.cepr.org

CEPR Discussion Paper No. 9111

September 2012

ABSTRACT

Sources of Comparative Advantage in Polluting Industries*

We study the determinants of comparative advantage in polluting industries. We combine data on environmental policy at the country level with data on pollution intensity at the industry level to show that countries with laxer environmental regulation have a comparative advantage in polluting industries. Further, we address the potential problem of reverse causality. We propose an instrument for environmental regulation based on meteorological determinants of pollution dispersion identified by the atmospheric pollution literature. We find that the effect of environmental regulation on the pattern of trade is causal and comparable in magnitude to the effect of physical and human capital.

JEL Classification: F11, F18, Q53 and Q56
Keywords: air pollution, comparative advantage, environmental regulation and international trade

Fernando A Broner
CREI
Universitat Pompeu Fabra
Ramon Trias Fargas 25-27
08005 Barcelona
SPAIN

Email: fbroner@crei.cat

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=159793

Paula Bustos
CREI
Universitat Pompeu Fabra
Ramon Trias Fargas 25-27
08005 Barcelona
SPAIN

Email: paula.bustos@upf.edu

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=166007

Vasco M Carvalho
CREI
Universitat Pompeu Fabra
Ramon Trias Fargas, 25-27
08005 Barcelona
SPAIN

Email: vcarvalho@crei.cat

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=161481

*We thank Bruno Caprettini for superb research assistance. We received valuable comments from David Atkin, Gene Grossman, Rema Hanna, Elhanan Helpman, Wolfgang Keller, Carol McAusland, Giacomo Ponzetto, Daniel Sturm, Scott Taylor, Jaume Ventura and participants at presentations held at Central European University, CREI, ERWIT, INSEAD, NBER-Summer Institute's Environmental and Energy Economics Workshop, Princeton IES Summer Workshop, Universidad Carlos III, Universitat Pompeu Fabra, and Université Toulouse. We thank Isabelle Morin from Abt Associates for her help in obtaining the pollution intensity data. We acknowledge financial support from the Fundación Ramón Areces, the Spanish Ministry of Science and Innovation, and the European Research Council (FP7/2007-2013, grant 263846).

Submitted 23 August 2012

1 Introduction

During the last few decades, many countries adopted environmental regulations in order to limit the emission of pollutants. The fact that these regulations vary across countries suggests the possibility that environmental regulation affects the location of polluting activities. In particular, if stricter environmental regulation increases the relative cost of production for polluting industries, one would expect these to relocate to countries with laxer regulation. In other words, lax environmental regulation is a potential source of comparative advantage in polluting industries. This effect is known in the literature on trade and the environment as the *pollution haven effect*.

The existence and strength of this effect is crucial for a number of questions of high policy relevance. Does strict environmental regulation lead to the relocation of particular industries, thus producing losses to the regions or factors of production that rely heavily on those industries? Do environmental regulation differences lead to the concentration of polluting activities in countries with lax regulation, particularly developing countries? Can environmental policy be used as an instrument to carry out trade policy? The policy discussions leading up to NAFTA and, in particular, the inclusion of specific clauses dissuading NAFTA members from "encourag(ing) investment by relaxing [...] environmental measures" (see Article 1114 of NAFTA) seem to point in that direction. In the same vein, efforts to harmonize standards across E.U. countries are often justified by the need to insure that environmental regulations do not distort competition.[1] Finally, discussions on whether - and to what degree - environmental standards can be cited as a rationale for applying trade-restricting regulations have been a recurrent feature of GATT/WTO negotiations.

Despite the theoretical appeal and policy relevance of the pollution haven effect, there is still no consensus about its economic significance. The traditional view in the trade and environment literature is that the effect of environmental regulation on comparative advantage in polluting industries is small and unimportant relative to traditional determinants of comparative advantage, such as capital abundance.[2] Our empirical results question this view. We combine data on environmental policy at the country level with data on pollution intensity at the industry level to show that countries with laxer environmental regulation have a comparative advantage in polluting industries. In addition, we address the potential problem of reverse causality. To do so, we propose an instrument for environmental regulation based on exogenous meteorological determinants

---

[1] See, for example, the European Court of Justice ruling in case C-300/89, Commission v Council: "provisions which are made necessary by considerations relating the the environment and health may be a burden and, if there is no harmonization of national provisions on the matter, competition may be appreciably distorted." (European Court of Justice, [1991]).

[2] See Grossman and Krueger (1993), Antweiler et al. (2001) and, for a survey of the empirical evidence, Copeland and Taylor (2004). We review the literature in detail below, including more recent contributions.

of pollution dispersion identified by the atmospheric pollution science literature. We find that the effect of environmental regulation on comparative advantage in polluting industries is causal and comparable in magnitude to the effect of physical and human capital endowments.

To guide 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, we treat pollution as another factor of production, whose relative supply is determined by environmental policy; see Copeland and Taylor (2003).[3] The model illustrates how lax environmental regulation is associated with a comparative advantage in polluting industries. Further, the model differentiates between emissions, which are a function of technology and the size of polluting industries, and pollution concentration, which is what affects the utility of households. The link between the two depends on meteorological conditions affecting the dispersion of pollution. In particular, a given level of emissions is associated with lower pollution concentration in countries with favorable meteorological conditions. The model shows that the optimal environmental policy is laxer in such countries. This result motivates our choice of instrument for environmental policy.

Turning to our empirical strategy, we extend the standard cross-country, cross-industry methodology proposed by Romalis (2004) to study the determinants of comparative advantage.[4] 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 have a comparative advantage in polluting industries. An advantage of this procedure is that it allows us to answer this question more broadly than existing studies that tend to focus on particular industries or trading partners. Further, it allows us to control for additional sources of comparative advantage.

We find evidence that environmental regulation is an important source of comparative advantage. That is, we show that countries with laxer environmental regulation systematically display higher U.S. import market shares in polluting industries than in other industries. To assess the magnitude of the effect of environmental regulation on market shares implied by our estimates, we perform the following quantification exercise. We use the sample median to divide countries into lax versus strict air pollution regulation. Similarly, we group industries into those that are more pollution intensive than the median and those that are not. Now consider taking the average lax air pollution regulation country and enacting a reform such that the policy stance would be that

---

[3] Early theoretical contributions to the trade and the environment literature include: Pethig (1976), McGuire (1982), Chichilnisky (1994), Copeland and Taylor (1994 and 1995).

[4] This approach has been used to study a variety of sources of comparative advantage. See below for a brief discussion of this literature.

of the average strict regulation country. What would happen to its market share in the average polluting industry relative to the average non-polluting industry? Our estimates imply that the difference in market shares would decrease by 0.08 percentage points. The equivalent effects for the classical determinants of comparative advantage are 0.17 percentage points for capital abundance and 0.20 for skill abundance. To put these figures in perspective, note that the average country commands a market share of 1.25 percentage points in the average industry.

An important concern regarding the interpretation of the OLS results described above is the direction of causality. For example, suppose a country has a comparative advantage in polluting industries because it is abundant in some unobserved input. Then, these industries might lobby more successfully to prevent the enactment of stringent environmental regulations. This would imply that comparative advantage in polluting industries causes laxer environmental policy, leading to a positive bias in our OLS estimates. 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.[5] 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).

The rationale for the choice of instrument is provided by our model, which predicts that optimal environmental policy is laxer in countries where meteorological conditions facilitate the dispersion of pollutants in the atmosphere. To identify the meteorological determinants of pollution dispersion we turn to the literature on atmospheric pollution. This literature has identified two main forces acting on the dispersion of pollutants in the atmosphere: wind speed, which determines horizontal dispersion of pollution; and mixing height, which determines the height within which pollutants disperse. These two elements are key components of models used to predict pollution concentration. In particular, in the simplest model of atmospheric pollution - the “Box model” (see Arya [1998] for a textbook treatment) - pollution concentration is inversely proportional to the product of wind speed and the mixing height, known as the “ventilation coefficient.” The Box model thus provides us with a simple measure for assessing 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.

In a nutshell, our instrumental variables strategy is based on the following hypothesis: where meteorological conditions are such that the dispersion of pollutants in the atmosphere is facilitated

---

[5] For example, List and Sturm (2006) report evidence showing that citizens’ environmental concerns affect environmental policy in the United States.

- i.e. countries with high ventilation coefficient - the marginal cost of emissions is lower and, as a result, optimal air pollution regulation tends to be laxer. Consistent with the model, we find that the ventilation coefficient is a strong predictor of country-level air pollution regulation. We argue that the ventilation coefficient satisfies the exogeneity requirement because it is determined by exogenous weather and geographical characteristics. Additionally, the exclusion restriction is likely to be satisfied as the ventilation coefficient is not correlated with other determinants of comparative advantage such as capital and skill abundance.

Our baseline two-stage least squares (2SLS) estimates of the effect of environmental regulation on comparative advantage in polluting industries are 80 percent higher than the corresponding OLS estimates. This finding suggests a negative bias in our OLS estimates, possibly due to reverse causality or to measurement error in our proxy for air pollution regulation. Taken together, the evidence presented in this paper suggests that the effect of environmental regulation on the pattern of trade is causal and comparable in magnitude to the effect of physical and human capital.

Related Literature:

We contribute to a rich literature studying the role of environmental regulation on comparative advantage. The literature has developed a series of empirical approaches to study the effect of differences in environmental regulation across countries in the pattern of trade.

In one of the most influential early studies, Grossman and Krueger (1993), inquire whether free trade between Mexico and the U.S. can lead to a reallocation of pollution-intensive industries towards Mexico, the country with laxer environmental regulation.[6] They propose to measure the pollution intensity of an industry as the share of pollution abatement costs (PAC) in value added, in the same way that labor intensity is measured by the share of wages in value added. They find that Mexico tends to export relatively more in labor intensive industries, but not in pollution intensive industries, concluding that the costs involved in complying with environmental laws are small in relation to the other components of total cost that determine comparative advantage.

We see our work as a generalization of the cross-sectional comparative advantage test in Grossman and Krueger (1993) to a broad cross-section of countries. Like them, we test whether differences in environmental regulation across countries generate comparative advantage in pollution-intensive industries. We differ from them in three dimensions. First, we use a broad cross-section of countries and a direct country-level measure of environmental policy. Second, we use emissions per unit of output to measure industry-level pollution intensity rather than relying on PAC which do not fully reflect the capital costs of complying with regulations.[7] Third, we analyze data from recent periods

---

[6] Two important early contributions to the literature are Kalt (1988) and Tobey (1990).

[7] The capital costs of complying with regulations are hard to measure because it is difficult to separate them from

where trade with developing countries became more important. As a result of these differences, we reach opposite conclusions: we find a sizable effect of environmental regulation in comparative advantage in polluting industries, comparable in magnitude to the effect of the traditional determinants of comparative advantage.

A second strand of the literature has focused on understanding how increased environmental regulation stringency in the U.S., following the Clean Air Act, affected U.S. comparative advantage (Ederington and Minier [2003], Ederington et al. [2005] and Levinson and Taylor [2008]). These papers exploit the differential changes in PAC across time within industries to identify the effect of environmental regulation on imports. Note that their use of PAC differs from that in Grossman and Krueger (1993). The latter interpret variation in PAC across industries as differences in pollution intensity, a technological characteristic of each industry. In contrast, the recent literature interprets variation in PAC across time as industry-level changes in environmental regulation stringency. The typical finding is that U.S. industries facing larger increases in pollution abatement costs experienced either small or statistically insignificant increases in imports. Ederington et al. (2005) argue that this might be due to the aggregation of trade flows across multiple countries. Indeed, they find that U.S. industries where pollution abatement costs increased more saw faster increases in imports from developing countries. However, it is unclear whether this finding is due do laxer environmental regulation. First, estimates are not statistically significant when they compare countries with lax vs. strict environmental standards. Second, they find that "the effect of an increase in environmental costs is actually smaller in the more pollution-intensive industries" (Ederington et al. [2005], p. 97). This puzzling result might be related to the simultaneous use of changes in PAC across time as a measure environmental regulation and levels of PAC as a measure of pollution intensity. Indeed, Levinson and Taylor (2008) argue that changes in PAC within an industry are not good measures of changes in environmental regulation. In particular, they propose a model where more stringent regulation causes the more polluting activities within an industry to migrate to other countries, and show that this compositional effect can generate a negative correlation between imports and changes in PAC.[8]

---

standard cost of capital. An example would be a situation in which a new facility needs to be built to comply with environmental regulations. For a detailed discussion of the problems related to measurement of the capital cost part of PAC see Levinson and Taylor (2008).

[8] Levinson and Taylor (2008) also analyze the relationship between imports and PAC using panel data. They find that increases in PAC during the period from 1977 to 1986 are associated with a small increase in imports from Mexico and Canada. They argue that these results are likely to be downwards biased due to the endogeneity of PAC. Thus, they instrument industry-level changes in PAC with changes in both income per capita and emissions in the states where the corresponding industry is located. This instrumentation strategy leads to larger estimates. However, these instruments might not satisfy the exogeneity and exclusion restrictions. For example, the adoption of an advanced technology that is less polluting in a given industry would reduce emissions in the state where the industry is located, the share of PAC in value added, and imports in that industry.

In sum, the common finding of the recent literature is that OLS estimates of the effect of increases in pollution abatement costs on import penetration in the U.S. are at best small. In contrast, our OLS estimates imply that environmental regulation is a source of comparative advantage in polluting industries and that its effect is comparable in magnitude to the classical determinants of comparative advantage. The difference in results can be explained by a shift in focus from the determinants of U.S. comparative advantage to the study of a broad cross-section of countries. This allows us to implement an empirical strategy that exploits differences across countries in environmental regulation stringency and differences across industries in pollution intensity. This additional country-level source of variation allows us to overcome a problem stressed by the recent literature: pollution abatement costs are not a good measure of technological characteristics of industries nor of environmental policy stringency as they are affected by both variables simultaneously (for a formal discussion see Levinson and Taylor [2008]).

Our work is also related to the literature studying the effect of environmental regulation on the location of industrial activity within the U.S. Henderson (1996), Becker and Henderson (2000), Greenstone (2002), and List et al. (2003) find that polluting industries have tended to relocate to U.S. counties where environmental oversight was less strict. These studies exploit variation in regulatory oversight caused by the Clean Air Act's classification of counties into attainment and non attainment status with respect to national air quality standards. We perform a similar comparative statics exercise in the sense that we compare the effect of differences in environmental regulation across geographical units on the level of activity of industries that differ in their pollution intensity.[9] While the size of the estimates is not directly comparable, taken together our findings suggest that the elasticity of output in polluting industries with respect to environmental regulation is large not only across U.S. counties but also across countries.

We also contribute to the literature by proposing an instrument for environmental regulation based on meteorological conditions identified by the atmospheric pollution science literature. In our view this instrument helps to solve the problem of identifying the causal effects of environmental regulation on economic outcomes. While several authors have emphasized the biases caused by the endogeneity of environmental policy, to the best of our knowledge, the literature has not identified an instrument for environmental policy satisfying the exogeneity requirement and the exclusion restriction.[10] In particular, although early on, Grossman and Krueger (1995) stressed

---

[9] Relatedly, Keller and Levinson (2002) show that U.S. states whose environmental regulation became relatively laxer in the period 1977-1994 showed a relative increase in inward foreign direct investment in manufacturing. Hanna (2010) studies the effect of the Clean Air Act Amendements on American multinational's and finds that it lead to an increase in their foreign assets and output. Other recent studies of the effect of environmental regulation on FDI are Kellenberg (2009) and Wagner and Timmins (2009).

[10] For a discussion of the difficulties in identifying a causal effect of environmental regulation due to the endogeneity

the importance of atmospheric conditions in determining pollution concentration outcomes, this has not been exploited as a source of variation in environmental policy. Notice also that while in this paper we exploit cross-country variation in atmospheric conditions to instrument for a country's environmental policy, the instrument we propose could also be applied to smaller geographical units. For example, it could help isolate the sources of environmental policy variation across U.S. counties. Indeed, Greenstone (2002) notes that the Clean Air Act's classification of counties into attainment and non attainment status depends on pollution levels which are partly related to endogenous local manufacturing sector activity but also partly driven by exogenous weather patterns. Our instrumentation strategy can then be used to isolate the part of variation in environmental regulation across U.S. counties that is exogenously determined by weather conditions.[11]

Finally, methodologically our paper is closest to a growing literature studying sources of comparative advantage. Like us, this literature has applied the cross-country, cross-industry methodology proposed by Romalis (2004). A number of papers have emphasized the importance of institutional factors. In particular, Manova (2008) focuses on financial development and Levchenko (2007), Nunn (2007) and Costinot (2009) focus on contract enforcement. Finally, Cuñat and Melitz (2012) stress the importance of labor market policies. Relative to these, we emphasize the importance of environmental policy as a source of comparative advantage in polluting industries.

The paper is organized as follows. Section 2 presents the theoretical model. Section 3 describes our empirical strategy and data sources. Section 4 presents our OLS and 2SLS estimates. Section 5 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 affects comparative advantage in polluting industries. The model describes a world with many countries, two tradable goods, one clean and one dirty, and two factors of production, labor and clean air. The clean good is labor intensive and the dirty good is clean-air intensive. Lax environmental regulation corresponds to allowing firms to use up a large amount of clean air. As a result, countries with lax environmental regulation have a comparative advantage in the dirty good.

---

of policy see Copeland and Taylor (2004), Damania, Fredriksson and List (2003), Ederington and Minier (2003) and Levinson and Taylor (2008).

[11] List et al. (2003) come closest to executing such strategy by exploiting variation in the attainment status of neighboring counties and wind direction. Although they do find a strong first stage, their instrumented county-level attainment status has no impact on the location of activity on a county's plant births.

The model also shows how environmental policy itself depends on country characteristics. In particular, we focus on whether countries are subject to meteorological conditions that facilitate the dispersion of pollutants. Dispersion of pollutants is faster in countries with a high *ventilation coefficient*, and thus these countries can be thought of as having a large endowment of clean air. The model shows that in these countries the optimal policy is to allow firms to use up a large amount of clean air, so their environmental regulation is lax.

2.1 Setup

The world is composed of many small countries, indexed by $j \in J$. Labor is the only factor of production. There is a mass one of residents in each 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 generate emissions. Labor productivity in country j is A_j, so that

$$Q_{cj} = A_j \cdot L_{cj} \quad \text{for} \quad j \in J, \tag{1}$$

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

$$E_{dj} = A_j^{-\gamma} \cdot Q_{dj} \quad \text{for} \quad j \in J, \tag{2}$$

where E_{dj} denotes emissions generated in the dirty industry and Q_{dj} denotes production of the dirty good. The parameter $\gamma \in [0, 1]$ captures the extent to which countries with higher productivity also have access to less polluting technologies. Inverting equation (2), we obtain

$$Q_{dj} = A_j^{\gamma} \cdot E_{dj} \quad \text{for} \quad j \in J. \tag{3}$$

As a result, we can reinterpret technology as production of the dirty good requiring clean air as an input instead of as generating pollution as a by-product.[12]

Pollution concentration in country j depends not only on the level of local emissions but also on how fast pollutants disperse in the atmosphere. In particular, pollution concentration in country j is equal to

$$Z_j = \frac{E_j}{V_j} \quad \text{for} \quad j \in J, \tag{4}$$

---

[12] This interpretation is common in the literature on trade and the environment. See Copeland and Taylor (2003) for a textbook analysis.

where V_j denotes the ventilation coefficient of country j. The functional form of the equation determining pollution concentration is derived from the Box model of atmospheric pollution dispersion, which we discuss in detail in the next section.

Utility is increasing in consumption of the clean and dirty goods and decreasing in pollution concentration:

$$U_j\left(C_{cj}, C_{dj}, Z_j\right) = U\left(C_{cj}^{\alpha_c} \cdot C_{dj}^{\alpha_d}\right) - W\left(Z_j\right) \quad \text{for} \quad j \in J, \tag{5}$$

where $\alpha_c + \alpha_d = 1$, $U' > 0$, $U'' < 0$, $W' > 0$, and $W'' > 0$.

Producing the dirty good is associated with a negative local externality. We assume that countries address this externality by imposing emission limits. This is realistic as environmental policy often takes the form of quantity limits as countries impose restrictions on the location and size of different industries.[13,14] In particular, we assume that each country j imposes a cap on emissions,

$$E_j \leq \bar{E}_j \quad \text{for} \quad j \in J. \tag{6}$$

These emission limits are implemented by distributing $\bar{E}_j$ emission rights to each resident of country j.[15]

2.2 Equilibrium

To obtain the equilibrium we proceed in two steps. First, we solve the model for a given pattern of emission limits $\bar{E}_j$ for $j \in J$. Second, we find the equilibrium emission limits. These are chosen optimally by each country, taking into account the emission limits chosen by other countries and the resulting goods prices. The first step is very simple. Given emission limits, the model is isomorphic to a two-good, two-factor model in which emissions are a second factor of production as opposed to a by-product.

Let P_c and P_d denote the prices of the clean and dirty goods respectively. Since $P_d > 0$, constraint (6) is binding and production is given by

$$Q_{cj} = A_j \cdot L \quad \text{and} \quad Q_{dj} = A_j^{\gamma} \cdot \bar{E}_j \quad \text{for} \quad j \in J, \tag{7}$$

---

[13] For example, this is the case for the Clean Air Act in the U.S. When pollution concentration reaches certain limits in a given county, that county becomes nonattainment, which triggers strong policy responses. For a detailed description of air pollution regulation in the U.S. see Greenstone (2002).

[14] In the literature on trade and the environment, environmental policy is often implemented as an emission tax, although it would be equivalent to implement it as a quantity restriction. That is because the different distributional effects of the two are not captured by representative agent models. In our model, though, environment policy cannot be implemented as an emission tax. The reason is that, given our strong simplifying assumptions, the elasticity of emissions with respect to the emission tax would be infinite.

[15] In the context of our model, imposing limits on pollution concentration has the same effect as imposing limits on emissions, as equation (4) implies a one-to-one relation between the two.

where we have imposed the market clearing condition $L_{cj} = L$. Let $I_j\left(\bar{E}_j\right)$ denote the income of the residents of country j as a function of emission limits $\bar{E}_j$, which is given by

$$I_j\left(\bar{E}_j\right) = P_c \cdot A_j \cdot L + P_d \cdot A_j^{\gamma} \cdot \bar{E}_j \quad \text{for} \quad j \in J. \tag{8}$$

With Cobb-Douglas preferences, consumption is given by

$$C_{cj} = \frac{\alpha_c \cdot I_j\left(\bar{E}_j\right)}{P_c} \quad \text{and} \quad C_{dj} = \frac{\alpha_d \cdot I_j\left(\bar{E}_j\right)}{P_d} \quad \text{for} \quad j \in J. \tag{9}$$

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

$$\frac{P_d}{P_c} = \frac{\alpha_d \cdot \int_{j \in J} A_j \cdot L}{\alpha_c \cdot \int_{j \in J} A_j^{\gamma} \cdot \bar{E}_j}. \tag{10}$$

We normalize prices so that the price of the "composite good" is one.[16] Under this normalization, goods prices are

$$P_c = \alpha_c \cdot \left(\frac{\int_{j \in J} A_j^{\gamma} \cdot \bar{E}_j}{\int_{j \in J} A_j \cdot L}\right)^{\alpha_d} \quad \text{and} \quad P_d = \alpha_d \cdot \left(\frac{\int_{j \in J} A_j \cdot L}{\int_{j \in J} A_j^{\gamma} \cdot \bar{E}_j}\right)^{\alpha_c}. \tag{11}$$

The welfare of country j is a function of its emission limits and is given by

$$U_j\left(\bar{E}_j\right) = U\left(I_j\left(\bar{E}_j\right)\right) - W\left(V_j^{-1} \cdot \bar{E}_j\right) \quad \text{for} \quad j \in J. \tag{12}$$

Equations (7), (9), (11), and (12) describe the equilibrium for a given pattern of pollution limits $\bar{E}_j$ for $j \in J$.

Since countries are small, we can analyze the effects of country characteristics taking goods prices as given. In particular, consider an increase in emission limits $\bar{E}_j$. Equations (7) and (9) show that Q_{cj} is unaffected and Q_{dj}, C_{cj}, and C_{dj} increase. The following result follows:

Result 1 (Pollution Haven Effect)**.** *Countries with higher emission limits export less of the clean good and more of the dirty good:*

$$\frac{d}{d\bar{E}_j}\left(Q_{cj} - C_{cj}\right) < 0 \quad \textit{and} \quad \frac{d}{d\bar{E}_j}\left(Q_{dj} - C_{dj}\right) > 0.$$

We now turn to the determination of emission limits. Country j chooses $\bar{E}_j$ to maximize its

---

[16] The price of the composite good is $\min\left\{P_c \cdot C_c + P_d \cdot C_c \,|\, C_c^{\alpha_c} \cdot C_d^{\alpha_d} = 1\right\}$. It is equal to one if $P_c^{\alpha_c} \cdot P_d^{\alpha_d} = \alpha_c^{\alpha_c} \cdot \alpha_d^{\alpha_d}$.

welfare in equation (12), taking as given goods prices P_c and P_d. The optimum $\bar{E}_j^*$ is determined implicitly by the first order condition

$$0 = V_j \cdot P_d \cdot A_j^{\gamma} \cdot U'\left(I_j\left(\bar{E}_j^*\right)\right) - W'\left(V_j^{-1} \cdot \bar{E}_j^*\right) \quad \text{for} \quad j \in J. \tag{13}$$

This condition shows that countries trade off the increase in income resulting from allowing an additional unit of emissions with the utility cost associated with the resulting increase in pollution concentration.

How do optimal emission limits $\bar{E}_j^*$ depend on the ventilation coefficient V_j? Once again, since countries are small we can analyze the effect of V_j taking as given goods prices. Take the total derivative of Equation (13) with respect to V_j and rearrange to obtain

$$\frac{d\bar{E}_j^*}{dV_j} = \frac{P_d \cdot A_j^{\gamma} \cdot U'\left(I_j\left(\bar{E}_j^*\right)\right) + V_j^{-2} \cdot \bar{E}_j^* \cdot W''\left(V_j^{-1} \cdot \bar{E}_j^*\right)}{V_j^{-1} \cdot W''\left(V_j^{-1} \cdot \bar{E}_j^*\right) - V_j \cdot P_d^2 \cdot A_j^{2 \cdot \gamma} \cdot U''\left(I_j\left(\bar{E}_j^*\right)\right)}. \tag{14}$$

From the properties of $U(\cdot)$ and $W(\cdot)$ it follows that both the numerator and the denominator are positive. The following result follows:

Result 2 (Ventilation Coefficient and Policy)**.** *Countries with a higher ventilation coefficient V_j impose higher emission limits $\bar{E}_j^*$:*

$$\frac{d\bar{E}_j^*}{dV_j} > 0. \tag{15}$$

The intuition behind this result is as follows. A higher ventilation coefficient means that a given level of emissions results in lower pollution concentration. Thus, in countries with high ventilation coefficients it is less costly in terms of pollution concentration to raise emission limits in order to increase income.

How do optimal emission limits $\bar{E}_j^*$ depend on productivity A_j? In principle, this is ambiguous because there are two opposing effects. On the one hand, a higher A_j has a positive income effect. This leads to lower emission limits to reduce pollution concentration and increase consumption of clean air. On the other hand, a higher A_j has a substitution effect that leads to higher emission limits since producing the dirty good generates less emissions. The strength of the latter effect depends on γ. In the Appendix A we show the following result:

Result 3 (Productivity and Policy)**.** *Countries with higher productivity A_j impose lower emission limits $\bar{E}_j^*$,*

$$\frac{d\bar{E}_j^*}{dA_j} < 0, \tag{16}$$

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

This result shows that countries with higher income tend to have lower emission limits. This income effect on environmental regulation is well known in the literature. However, our model points to an important caveat. In our model income depends on both productivity and the ventilation coefficient. In particular, if two countries are equally productive, the one with the higher ventilation coefficient will impose higher emission limits, which will increase its income. Thus, it is only when controlling for the ventilation coefficient that countries with higher income will tend to have lower emission limits.

To conclude the analysis in this section, let us make a few remarks regarding the efficiency of environmental policy. In the model the equilibrium is efficient because of two important assumptions. First, pollution externalities are only local. As a result, countries have an incentive to fully internalize the negative effects of their emissions when setting environmental policy. This assumption is reasonable for the pollutants analyzed in this paper. But it would not be reasonable, for example, for greenhouse gas emissions, where international coordination plays a crucial role. Second, countries choose policy optimally and are able to enforce it. This assumption is reasonable for countries with strong institutions, but less so for countries where political economy considerations can bias policy choice and where lack of resources can restrict governments' ability to enforce environmental policy.

3 Empirical strategy and data sources

The model presented above guides empirical work by delivering two clear predictions. First, conditional on other determinants of comparative advantage, countries with less stringent environmental policy will have a comparative advantage in polluting industries. Second, environmental policy will be less stringent in countries where meteorological conditions are such that pollution emissions are more easily dispersed in the atmosphere.

To assess the empirical content of these predictions, we extend the standard cross-country, cross-industry methodology proposed by Romalis (2004) to study the determinants of comparative advantage in polluting industries. 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. To motivate this empirical strategy, recall that the model in Section 2 - and much of the literature on trade and the environment - treats pollution as another input in production. We thus treat pollution intensity as a technological characteristic of an industry, in the same way we treat its capital and skill intensity. Further, in our model, regulation is implemented as a quantity restriction determining the total amount of clean air that is available for use as an input in production.[17] Therefore, we treat environmental regulation in the same way that we treat capital and skill abundance. Our empirical specification then takes the form:

$$M_{ic} = \beta_1 \; E_c \times e_i + \beta_2 \; K_c \times k_i + \beta_3 \; H_c \times h_i + \alpha_c + \alpha_i + \varepsilon_{ic}, \tag{17}$$

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; e_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. Result (1) in Section 2, namely that a country with laxer environmental regulation should export relatively more in polluting industries, would correspond to finding $\beta_1 > 0$.

The model also shows how the stance of environmental policy depends on the prevalence of meteorological conditions that facilitate the dispersion of pollutants in the atmosphere. Wherever conditions are such that the dispersion of pollutants is fast, Result (2) indicates that the optimal policy is to allow firms to use up a larger amount of clean air, i.e. environmental regulation is laxer. This suggests an instrumental variables strategy, whereby exogenous cross-country variation in pollution dispersion potential leads to variation in the strictness of environmental policy. Notice also that if, as we argue below, this variation in pollution dispersion conditions does not affect other traditional determinants of comparative advantage - i.e. the exclusion restriction is met - we can use it to assess the direction of causality in regression (17). That is, by pinpointing a source of exogenous variation in environmental policy we can address whether laxer environmental policy leads to comparative advantage in polluting industries and not the reverse.

To implement the empirical strategy just described we use standard variable definitions and sources whenever possible. The dependent variable, country c's relative import shares (M_{ic}) into the U.S., is defined as country c's U.S. import share in sector i divided by the average share of country c in U.S. imports. This normalization, suggested by Romalis (2004), 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.[18] The data on U.S. imports refers to

---

[17] This interpretation is also appropriate in models in which regulation is implemented as a pollution tax. See Copeland and Taylor (2003) for details.

[18] For completeness, in Appendix D we show that we obtain similar coefficient estimates when we use the log of imports as our dependent variable.

manufacturing industries in 2005 and is sourced from Feenstra, Romalis and Schott (2002), updated to 2006.

Industry-level skill and capital intensity (h_i and k_i respectively) are measured using U.S. industry data. Under the assumption that there are no factor intensity reversals, U.S. industry characteristics are a good measure of differences in factor intensity across industries for all countries. Skill and capital intensity data are drawn from Bartelsman and Gray's (1996) NBER-CES manufacturing data, updated to 2005. Skill intensity of an industry is defined as one minus the share of wages of production workers. Capital intensity is measured as an industry's stock of physical capital per unit of value added. For measures of factor abundance at the country level, we use the stocks of human capital and physical capital per worker (H_c and K_c respectively) from Barro and Lee (2010) and the Penn World Tables (Heston, Summers and Aten, 2009), respectively.[19]

As discussed above we additionally need to obtain: i) a measure of air pollution intensity of an industry; ii) a measure of meteorological conditions determining a country's air pollution dispersion potential; and iii) a measure of the laxity of air pollution regulation of a country. In what follows we detail the sources of each of these measures.

3.1 A measure of air pollution intensity

We treat pollution intensity as a technological characteristic of an industry. That is, in the same way an industry can be characterized as capital intensive, we can also rank industries by how pollution intensive their production technologies are. In order to compute such a measure we turn to data derived from the Environmental Protection Agency's (EPA) National Emissions Inventory and obtain, for each manufacturing industry, total pollution emitted per unit of output.

In particular, our measure of air pollution intensity at the industry level is drawn from data compiled for the EPA's Trade and Environmental Assessment Model (TEAM).[20] TEAM's air emissions baseline data is in turn based on the EPA's 2002 National Emissions Inventory. From this data set, we obtain the total amount of air pollution emitted by 4-digit NAICS manufacturing industries in the U.S. in 2002. We focus our analysis on emissions of three criteria air pollutants: Carbon Monoxide (CO), Nitrogen Oxides (NOx) and Sulfur Dioxide (SO2). Given information on the value added of each industry we then compute the pollution intensity of each industry as total emissions per dollar of value added.

---

[19] We compute the stock of human capital following the method in Hall and Jones (1999). Physical capital per worker is obtained by applying the perpetual inventory method to investment data . See Appendix C for further details the sources and definitions of these and all other variables used in this paper.

[20] This data is assembled by the EPA and Abt Associates. See Abt Associates (2009) for a complete description. Levinson (2009) also uses TEAM-EPA data when computing measures of industry-level pollution intensity.

In total, we have pollution intensity data for 85 manufacturing industries. Table 1 summarizes the ten most pollution intensive industries in our data set. In particular, 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. More generally, and despite differences in the exact ordering of sectors across pollutant categories, computing a rank correlation reveals a high average correlation: pollution intensive industries in a given pollutant tend to be so in all pollutants (see Table 2).

Our list of the most pollution intensive manufacturing industries is broadly consistent with the ranking of "dirty industries" in Mani and Wheeler (1999) who rely - along with much of the published literature - on an alternative indicator of pollution intensity based on the older Industrial Pollution Projection System (IPSS) data set assembled by the World Bank.[21,22] Additionally, and just as Hettige et al. (1995) had noted for IPSS data, the distribution of industry-level pollution intensity derived from our TEAM-EPA data is fat tailed with a small number of highly pollutant sectors. For example, the least pollution intensive manufacturing sector in Carbon Monoxide - tobacco manufacturing- is 24 times less polluting than the most CO intensive industry, alumina and aluminum production.

Finally, it is important to understand how the pollution intensity of an industry correlates with other industry-level technological characteristics. Table 3 reports the correlation of our measures of an industry's pollution intensity and its capital and skill intensity. Across all pollutants, pollution intensive industries tend to be capital intensive and slightly unskilled intensive. The positive correlation between pollution intensive and capital intensive industries is again in accordance with the discussion in Mani and Wheeler (1999) for the IPSS data set.[23]

3.2 A measure of air pollution dispersion potential

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 concentration of pollutants is determined by winds, temperature profiles, cloud cover, and relative

---

[21] 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."

[22] At this degree of sectoral disaggregation, it is difficult to find comparable pollution intensity data for other countries. Still, Cole et al. (2005) and Dean and Lovely (2010), 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, petroleum and paper manufacturing.

[23] Antweiler et al (2001) make the same point based on pollution abatement cost data for the U.S..

humidity, which in turn depend on both small- and large-scale weather systems; see Jacobson, (2002), for a textbook treatment. Further, when the atmosphere's potential for pollution dispersion is limited acute air pollution episodes are likely to occur, posing significant risks to human health.[24]

Thus, depending on meteorological characteristics, two countries with the same industry mix and the same level of economic activity can have very different levels of pollution concentration in the atmosphere, and therefore rank differently in terms of the health outcomes of its citizenry. If, as it seems reasonable to assume, the stringency of environmental policy responds to the latter, we would expect that in countries where pollution is easily dispersed in the atmosphere air pollution regulation will not be as strict. The model presented in Section 2 illustrates this basic insight by showing that welfare maximizing environmental policies should indeed respond to the prevalence of meteorological conditions that facilitate air pollution dispersion.

In order to pinpoint meteorological variables that can potentially act as environmental policy shifters we turn to the large and established literature on air pollution meteorology. The latter is an integral part of environmental policy and monitoring. In the U.S., for example, the EPA routinely resorts to meteorological models both to monitor air quality and to predict the impact of regulation and new sources of air pollution.[25] 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.[26]

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 them. Second, pollution disperses vertically as a result of vertical movements of air, which result from temperature

---

[24] A notorious 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 and Jacobson [2002], p.88).

[25] 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." (EPA [2004], pp. 9-1).

[26] 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 currently in place.

and density vertical profiles.[27] 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.[28] 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.

In its simplest form, the Box 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 $\mathcal{L}$, which emits E 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 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 shown in Appendix B, this implies that the total amount of pollution within the box follows a simple differential equation. In steady state, the average concentration of pollution, Z, in the urban area is given by

$$Z = \frac{\mathcal{L}}{2} \cdot \frac{E}{u \cdot h}. \tag{18}$$

The product of wind speed and mixing height, $u \cdot h$, is known in the literature as the "ventilation coefficient".[29] The average concentration of pollution in the urban area is inversely proportional to its ventilation coefficient.[30] The Box model thus provides a simple metric to assess and compare the potential for air pollution dispersion 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 in pollution concentration is exogenous as it is determined to a large extent by weather systems.

The Box model has been successfully used in a variety of air quality applications. Up until recently, both the U.S. National Weather Service and the UK Meteorological Office used the Box

---

[27] That is, how air temperature and density varies with height in the atmosphere.

[28] 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 EPA (2005), or Jacobson, (2002), pp. 157-165 for further details.

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

[30] 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.

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 potential for health damaging pollution episodes in 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).

To the best of our knowledge, and despite its routine application in many countries, there is no readily available data set on the distribution of ventilation coefficients worldwide. To construct such data set, we source the necessary information on meteorological outcomes - wind and mixing height - from the European Centre for Medium-Term Weather Forecasting (ECMWF) ERA-Interim data set (Dee et al. [2011]). This data set is the latest version 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 weather outcomes on a global grid of $0.75^o \times 0.75^o$ cells, or roughly 83 square kilometers. ERA-Interim source data relies overwhelmingly on satellite observations (see Dee et al. 2011), thus ensuring global coverage of comparable quality across locations and time.[31,32]

For each month between January 1980 and December 2010 and for each cell, the ERA-Interim data set provides noon time averages for wind speed (at 10 meters above the ground) and mixing height[33] (in meters above the ground). By multiplying these two values, we construct a monthly series of ventilation coefficients. Since our focus is on long term meteorological characteristics, we average the monthly ventilation coefficient over the period January 1980 to December 2010.[34,35] Figure 1 maps the log of the resulting average ventilation coefficient.

The distribution of ventilation coefficients worldwide is the result of both large and small scale factors. Ventilation coefficients tend to be lower where both the depth of the mixing layer and wind speed are low. These are particularly low around the coasts of the Pacific ocean, due to the presence of semi-permanent high pressure systems. Conversely, in dry subtropical land regions, in particular in desert areas, mixing height tends to be high as a result of thermal low pressure

---

[31] 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.

[32] 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.

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

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

[35] Given the seasonality of meteorological conditions, as a robustness check, we have also constructed a "worst month of the year" series by selecting, for each cell, the month of the year where the average ventilation coefficient is lowest. The correlation with our baseline measure is high and all results go through.

systems. Therefore ventilation coefficients tend to be high. This is the case of most of North Africa and the Middle East as well as the desert regions of southern Africa. Most of Europe, West Africa and the Atlantic coast the Americas display intermediate ventilation coefficients.[36] Small scale factors, including altitude, ruggedness and soil type, introduce spatial variation within these broad patterns.

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.[37] To do this, we select the grid-cell where the capital city is located and assign to the latter the average ventilation of the corresponding cell.[38] We then take the ventilation coefficient of a country to be given by that of its capital. Henceforth, we denote this (country-level) measure of air pollution dispersion by V_c. Figure 2 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.[39]

Finally, we 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 there is no significant correlation between the ventilation coefficient of a country and its abundance in physical capital, human capital or its GDP per capita. The correlation of the ventilation coefficient with capital and skill abundance and GDP per capita is -0.01, -0.03 and -0.005, respectively. Further, none of these are significant at the 10% level. Our measure is only weakly correlated with oil reserves per capita and fertile land per capita (correlations of 0.14 and -0.15 respectively).[40]

---

[36] We are not aware of studies concerning global patterns of ventilation coefficients. However, our results are in line with the global patterns described by Von Engeln and Teixeira (2010) for mixing height and Archer and Jacobson (2005) and Lu, McElroy and Kiviluoma (2009) for wind speed.

[37] 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 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.

[38] 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.

[39] 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.

[40] We measure oil abundance as oil reserves per capita. The data on oil reserves is made available by the U.S. Energy Information Administration. Fertile land is defined as total land area of a country times its percentage of fertile soil and is sourced from Nunn and Puga (2012). For a more detailed description of these variables and their

3.3 A measure of air pollution regulation

Clean air is a textbook example of a public good. Absent any regulation, polluting industries would not internalize the environmental damages generated by their production activities and would thus overexploit the commons. By imposing limits on the amount of pollution emitted, environmental regulation therefore defines the total endowment of clean air that can be used as an input in production. This is made explicit in the simple model of Section 2 where regulation is implemented as air quantity restriction.

In the data however, a country's stance on air pollution regulation is a multidimensional object spanning a variety of policy measures such as emission caps, taxes on air-polluting activities or R&D subsidies targeting low emission technologies. Given the paucity of comparable cross-country data covering all these dimensions, such a measure is difficult to compute. Instead, we follow the literature in proxying for air pollution regulation with the only *actual* air pollution policy measure that is available for a broad cross-section of countries: grams of lead content per liter of gasoline.[41]

As Hilton and Levinson (1998) and Lovei (1998) discuss, lead emissions are toxic and pose 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 explicitly targeted reduction in lead emissions. Lead is defined by the EPA 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.

Tail-pipe emissions from vehicles fueled by leaded gasoline are the largest source of lead exposure. As a result, policies targeting lead pollution in the atmosphere have taken the form of legislation capping 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 with government officials.[42] 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.

---

sources refer to Appendix C.

[41] For studies using this policy measure see, for example, Hilton and Levinson (1998), Damania, Frederiksson and List (2003) and Cole, Elliot and Fredriksson (2006).

[42] 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. (1996), 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 other primary sources of data as discussed in the main text.

As discussed above, while admittedly narrow and applying primarily to industries relying heavily on transportation activities, lead content per liter of gasoline is, to the best of our knowledge, the only actual air pollution regulation measure 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.[43] Our lead content measure is also negatively correlated with other traditional determinants of comparative advantage like capital (correlation coefficient of -0.64) and skill abundance (coefficient of -0.69). This is as expected and reflects the fact that richer countries have tended to spearhead efforts in addressing atmospheric lead pollution. Indeed, 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, explicit government intervention in several middle and low income countries have also contributed to stringent policy being enacted in parts of the developing world. In our sample, this is the case of Bolivia or Thailand for example.

Finally, in the empirical analysis of Section 4 we will be exploiting the link between our measures of air pollution regulation and air pollution dispersion. In particular, recall that we will be using the latter as an exogenous source of variation in air pollution regulation stringency. With this is mind, and before pursuing an explicit instrumental variables strategy in a cross-country, cross-industry setup, it is useful to take a first look at the effect of the ventilation coefficient on country-level environmental regulation. Table 5 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. [44]

Note in particular that the inclusion of a control for GDP per capita in column 2 does not significantly affect the estimated effect of the ventilation coefficient on environmental regulation. That is, 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. The relationship between environmental regulation (E_c) on the ventilation coefficient (V_c) is illustrated in Figure 3,

---

[43] Relative to our policy measure the main drawback of these proxies is that they are available for a small number of countries only.

[44] 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 (World Bank [2004]). See Appendix C for a more detailed discussion

where country names are included. Fitted values correspond to the regression reported in column 2, where GDP per capita is included as a control.

4 Determinants of comparative advantage in polluting industries

In this section we investigate whether lax environmental regulation can be a source of comparative advantage in polluting goods. We test whether lax regulation countries capture larger shares of U.S. imports in polluting industries by estimating equation (17):

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

where E_c is a measure of the *laxity* of air pollution regulation in country c; e_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.

Our outcome of interest is the relative market share, M_{ic}, which measures a country c's comparative advantage by comparing its import market share in a given industry i to its average market share in U.S. imports. Thus, if a country had identical import market shares in all industries, M_{ic} would take the value of one for all industries. M_{ic} takes values larger (smaller) than one for industries where a country has an import market share that is larger (smaller) than its average import market share, that is, for industries where the country has a comparative advantage (disadvantage). Note that M_{ic} measures comparative advantage for all countries except the U.S., which only plays the role of the common market where we observe and compare the import market shares of all the other countries.

Note that the resulting estimation strategy follows the same logic as a standard differences-in-differences (DD) strategy. We compare the market shares in polluting relative to non-polluting industries across countries with lax and stringent environmental regulation. The difference between our estimates and a standard DD strategy is that we use a continuous measure of the intensity of treatment: the stringency of a country's environmental regulation. In addition, we have a continuous measure of the level of exposure to the treatment, namely an industry's pollution intensity. As a benchmark, note that the simpler DD estimates would directly answer the following question: is the share of exports in pollution intensive industries larger for countries with lax air pollution regulations? Anticipating the more detailed empirical analysis below, we start by answering this simpler question. For this purpose, we divide the sample into lax 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 it is in the top quartile of the distribution of total pollution intensities for that pollutant. We find that, for lax regulation countries, 51 percent of their manufacturing exports to the U.S. are in NOx intensive industries while for strict air pollution regulation countries 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 lax air pollution regulations tend to export relatively more in pollution intensive industries.

4.1 OLS estimates

We start by reporting estimates of the effect of environmental regulation on comparative advantage in polluting industries. Note, that, as discussed in Section 3.1, we measure industry-level pollution intensity as emissions per unit of output for three pollutants: sulfur dioxide (SO2), nitrogen oxides (NOx) and carbon monoxide (CO). Table 6 reports estimation of Equation (17) separately for each of these three air pollutants (without controlling for capital and skill interactions) for a sample of 101 countries and 85 industries. This table and all subsequent tables in the paper report standardized beta coefficients and robust standard errors.[45] The second column reports the estimate of β_1 for the interaction of NOx pollution intensity of the industry with the measure of lax air pollution regulation of the country. The third and fourth columns report the analogous estimation for SO2 and CO. Since these are beta coefficients they can be directly compared across pollutants. The estimated β_1 coefficients on the country's air pollution regulation and the industry's air pollution intensity interaction ($E_c \times e_i$) are positive and statistically significant at 1 percent for each pollutant. Note that the estimated effects are of a similar magnitude across pollutants. This is not surprising because, as discussed in Section 3.1, these pollution intensity measures are highly correlated as industries tend to be polluting across all three pollutants. Thus, to simplify the exposition, in what follows we only report estimates for the average pollution intensity across these three pollutants, which is reported in column 1.

4.1.1 Baseline estimates

Our baseline estimation of Equation (17) with controls for factor endowments and other determinants of comparative advantage is reported in Table 7. Note that as the measure of human capital endowment is only available for a subset of 73 countries, the sample is smaller than in Table 6.

---

[45] In Appendix D we show that all coefficient estimates are also precisely estimated when clustering errors across countries and industries.

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 ($E_c \times e_i$) is not capturing the effects other classical determinants of comparative advantage. The estimated coefficient on the pollution interaction reported in column 2 implies that if a country moves from the mean to a one standard deviation below the mean air pollution regulation, the difference in relative market shares between an industry that is one standard deviation above the mean pollution intensity and the mean industry increases by 8.3% of a standard deviation. The equivalent estimates for the capital intensity and skill intensity interactions are 5.1% and 6.6%.

Our estimates imply that lax regulation countries systematically display higher U.S. import market shares in polluting industries. To quantify the effect of environmental regulation on market shares we divide the sample into lax versus strict air pollution regulation countries, defined as those with a measure of lax air pollution regulation, above and below the sample median, respectively. Similarly, we group industries into those that are more pollution intensive than the median and those that are not. Now consider taking the average lax air pollution regulation country and enacting a reform such that the policy stance would be that of the average strict regulation country. What would happen to its market share in the average polluting industry relative to the average non-polluting industry? Our estimates imply that the difference in market shares would decrease by 0.08 percentage points. The equivalent estimates for the classical determinants of comparative advantage are 0.17 percentage points for the capital intensity interaction and 0.20 for skill.[46] To put these numbers in perspective, consider that in this sample, the average country holds a market share of 1.25 percentage points in the average industry.

Finally, let us highlight that we find that countries with lax environmental regulation have a comparative advantage in polluting industries even without controlling for other sources of comparative advantage. Moreover, the estimated effect of environmental regulation on comparative advantage in polluting industries is stable when we include controls for the capital and skill in-

---

[46] This is calculated as follows. The level of air pollution regulation of an average lax country is given by $E_c^{Lax} = 0.552$, the simple average of E_c over all countries whose environmental stance is laxer than the world median. The level of air pollution regulation of an average strict country is defined analogously and given by $E_c^{Strict} = 0.049$. Thus the decrease in air pollution regulation laxity when moving from an average lax country to an average strict country is given by $E_c^{Strict} - E_c^{Lax} = -0.503$. Similarly, define the level of pollution intensity of an average polluting (non-polluting) industry as the average e_i over all industries above (below) the median industry pollution intensity. This gives $e_i^P - e_i^{NP} = 1.1663$. The beta coefficient of 0.083 in Table 6 corresponds to a non-normalized coefficient of 0.632. Thus, in terms of our outcome variable, M_{ic}, the effect of the policy reform discussed in the text would be $0.632 \times (E_c^{Strict} - E_c^{Lax}) \times (e_i^P - e_i^{NP}) = -0.371$. Recall that given our normalization for country size, this number is in units of the average market share of the average lax country. In the data, the latter is 0.2 percent. Thus, the difference in market shares between polluting and non-polluting industries when moving from lax to strict regulation is given by $-0.371 \times 0.2 = -0.08$ percentage points. The numbers cited for capital and skill are calculated in an analogous way.

tensity interactions. This suggests that exploiting variation across countries in factor abundance and variation across industries in factor intensity allows us to isolate the effect of environmental regulation on comparative advantage. This helps overcome an important problem highlighted by the earlier literature: as countries with lax environmental regulation are usually capital scarce and capital intensive sectors tend to be polluting, it is hard to differentiate the effect of environmental regulation on exports of polluting goods from the effect of capital abundance in exports of capital intensive industries.

4.1.2 Robustness

A potential problem in the estimation of Equation (17) 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]). This leads to a positive correlation between environmental regulation and certain country characteristics. If pollution intensity is also correlated with the corresponding industry characteristics, the omission of these other determinants of comparative advantage can bias the estimated effect of environmental regulation. We assess the importance of this omitted variable problem by evaluating the robustness of our estimates to the inclusion of controls for other sources of comparative advantage.

First, we control for the possibility that more technologically advanced countries specialize in industries where the pace of innovation is faster. For this purpose, we include an interaction between GDP per capita and measures of industry-level TFP growth or the value added share of output. This does not affect the estimated coefficient on the pollution interaction, as reported in Columns 2, 3 and 4 of Table 7. Similarly, we 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 5, 6 and 7 show that the estimated coefficient on the pollution interaction remains stable 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).[47]

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. For example, suppose that we do not have a good

---

[47] 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 the World Bank (2004).

measure of an industry's R&D intensity, which is negatively correlated with pollution intensity. The pollution interaction could then be capturing the fact that rich countries (stringent regulation) tend to specialize in R&D intensive industries (not polluting). To address this concern, we note that the worst case scenario would be one where the omitted industry characteristic is perfectly correlated with pollution intensity. But in this case, we could use pollution intensity itself as a proxy for the omitted industry characteristic. This is what we do: we include an interaction of the relevant country characteristic, in this case GDP per capita, and pollution intensity in the estimation of equation (17). Estimation results are reported in Table 8 where a comparison of columns 3 and 4 shows that the estimated effect of environmental regulation on exports of polluting goods increases by 30% when controlling for an interaction of GDP per capita and pollution intensity. Thus, if anything, pollution intensity seems to be positively correlated with omitted characteristics of industries that richer countries tend to specialize in, which tends to downward bias the estimated effect of environmental regulation on exports of polluting industries.

A second potentially important omitted source of comparative advantage is natural resources, as industries that are intensive in the use of natural resources might be more polluting. Recall that throughout we are excluding agriculture and mining from the analysis, as the location of those industries is largely determined by the availability of natural resources. A remaining difficulty is that some manufacturing industries rely on mining and agricultural goods as inputs. As most of these inputs are traded there is no a priori reason for industries to locate close to natural resources. Still, industries with higher transport costs for inputs than outputs might tend to locate close to natural resources. To address this concern we include controls for natural resource abundance of the country and the corresponding natural resource intensity of the industry whenever possible. For example, we construct an industry-level measure of oil intensity that we interact with country-level oil abundance.[48] When it is not possible to construct a measure of the relevant industry characteristic, we rely on the proxy discussed above: we use pollution intensity as a proxy for the omitted industry characteristic. For example, absent an industry-level measure of land intensity of inputs, we interact pollution intensity of the industry with the fertile land per capita of the country. Columns 4, 5 and 6 of Table 8 show 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 fertile land per capita, and oil intensity with oil abundance. These results suggest that environmental regulation is not capturing the effect of other country characteristic that influences comparative advantage in

---

[48] 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. For further details refer to Appendix C.

polluting industries.

Additionally, to address potential correlation in errors across subsets of industries or countries, we show in Appendix D that the estimated coefficients are also precisely estimated when clustering errors across countries and industries. Tables D1 and D2 replicate the coefficient estimates reported in Tables 7 and 8 but report standard errors clustered at the country-level. Similarly, Tables D6 and D7 report standard errors clustered at the industry and country-level.[49] Finally, in Tables D11 and D12 we show that we obtain similar coefficient estimates when using log imports instead of import market shares as our dependent variable. Recall that we prefer the specification in import market shares because that allows us to analyze the full sample where a third of the observations are zero.

4.2 Causality

In the previous section, we showed that countries with laxer environmental regulation have a comparative advantage in polluting industries. However, interpreting the OLS estimates as the causal effect of environmental regulation on comparative advantage faces the difficulties of reverse causality and joint determination. As an example of reverse causality, suppose a country has a comparative advantage in polluting industries because it is abundant in some unobserved input. Then, 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 in the estimated effect of environmental regulation on comparative advantage in polluting industries. 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. Moreover, our measure of environmental regulation, the lead content of gasoline, is an imperfect proxy for air pollution regulation as it only measures one of its dimensions. This can result in measurement error, which would also lead to a negative bias.

To address these concerns 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, we rely on the ventilation coefficient, which measures the speed at which pollutants disperse in the atmosphere, to construct an instrument for air pollution regulation. The rationale for our choice of instrument is illustrated by the model presented in Section 2, which predicts that countries with a higher ventilation coefficient face lower pollution

---

[49] We cluster standard errors simultaneously at the country and industry-level following the 2-way clustering methods developed by Cameron, Gelbach and Miller (2008).

concentration for a given level of emissions, thus tend to enact less stringent air pollution regulation.

Consistent with the model, we find that the ventilation coefficient is a strong predictor of country-level air pollution regulation. As discussed in Section 3.3., when we estimate a cross-country regression of environmental regulation on the ventilation coefficient we find that a one standard deviation increase in the latter produces a 22% of a standard deviation increase in the former, with estimates statistically significant at 1% and robust to the inclusion of controls for other country characteristics (see Table 5 and Figure 3).

The ventilation coefficient arguably satisfies the exogeneity requirement because it is determined by exogenous weather and geographical characteristics. To see this, recall that the ventilation coefficient is defined as the product of wind speed, which measures horizontal dispersion of pollutants, and mixing height, which measures vertical dispersion. Regarding the exclusion restriction, we argue that the ventilation coefficient only affects comparative advantage through its effect on air pollution regulation. To see this, recall that although the ventilation coefficient affects pollution concentration, the latter only affects comparative advantage through regulation because clean air is a public good. As a result, the shadow price of pollution emissions is determined by environmental regulation. Absent regulation, the shadow price of emissions would be zero for all levels of the ventilation coefficient. Therefore, the latter would not have a direct effect on comparative advantage in polluting industries, as firms would not have incentives to internalize the costs associated with pollution emissions.

A potential challenge to the exclusion restriction remains: the geographical and weather characteristics that determine the ventilation coefficient could influence not only pollution concentration but also a country's endowments of other production factors and then shape its comparative advantage through other channels. To address this concern, we report correlations between the ventilation coefficient and the main determinants of comparative advantage. The correlation coefficients between the ventilation coefficient and GDP per capita, capital and skill endowments are between -0.005 and 0.03 and not statistically different from zero (see Section 3.3). This absence of correlation between the ventilation coefficient and the main determinants of comparative advantage suggests that the exclusion restriction is satisfied. Still, we include them as controls in what follows.

Note that we only instrument for environmental regulation, E_c and not for the other element of the pollution interaction, namely pollution intensity e_i, in equation (17). This is because pollution intensity can be considered as exogenous with respect to our outcome of interest, the relative market share of country c in industry i, M_{ic}. To see this, recall that our pollution intensity measure is based on emissions per unit of output in the U.S.. Thus, the main potential concern is that it might not be exogenous to U.S. comparative advantage. However, our outcome of interest, M_{ic}, measures comparative advantage for all countries except the U.S., by comparing a country's U.S. import market share in a given industry i to its average market share in U.S. imports. That is, the U.S. only plays the role of the common market where we observe and compare the import market shares of all the other countries. By definition, the U.S. import market share in U.S. imports is zero for all industries, thus our outcome variable M_{ic} is independent of U.S. comparative advantage.

In sum, as pollution intensity is arguably exogenous with respect to our outcome of interest, and the ventilation coefficient is a valid instrument for environmental regulation, we can use the interaction of the ventilation coefficient in country c and pollution intensity in industry i ($V_c \times e_i$) as an instrument for the interaction of environmental regulation in country c and pollution intensity in industry i ($E_c \times e_i$) in equation (17).[50]

To simplify the exposition, we start by reporting the direct effect of the ventilation coefficient on comparative advantage or reduced form estimates. Next, we report our 2SLS estimates where we use the ventilation coefficient as an instrument for environmental regulation.

4.2.1 Reduced form estimates

In this section we estimate the reduced form effect of the ventilation coefficient 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. We thus estimate the following specification:

$$M_{ic} = \gamma_1 \; V_c \times e_i + \gamma_2 \; K_c \times k_i + \gamma_3 \; H_c \times h_i + \alpha_c + \alpha_i + \varepsilon_{ic}, \tag{19}$$

where V_c is the ventilation coefficient in the capital of country c, e_i is pollution intensity of industry i. Estimation results are reported in Table 9. 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%.[51]

As discussed above, the main concern in interpreting the estimates of γ_1 is that the geographical and weather characteristics that determine the ventilation coefficient could also influence a country's

---

[50] The requirements for this instrumentation strategy to be valid are that the ventilation coefficient is a valid instrument for environmental regulation, and pollution intensity is exogenous with respect to our outcome of interest. See Ozer-Balli and Sorensen (forthcoming) for a discussion of implementation of instrumental variable strategies in linear regressions with interaction terms. For a formal discussion, see also section 2.3.4 of Angrist and Krueger (1999).

[51] We report standardized beta coefficients and robust standard errors in Table 9. In Appendix D, we show that coefficient estimates remain precisely estimated when clustering standard errors across countries or across countries and industries (see tables D3 and D8, respectively). In table D13 we show similar estimates are obtained when using the log of imports instead of the import market share as our dependent variable.

endowments of other production factors and then shape its comparative advantage through other channels. To address this concern we assess the stability of the estimated γ_1 coefficient to the inclusion of controls. We start by reporting estimates for the largest sample of countries that has information on per capita GDP but not capital and skill endowments. The results reported in columns 1 and 2 of Table 9 show that the estimated γ_1 is unaffected by the inclusion of a control for the interaction of GDP per capita and pollution intensity. In addition, a control for the interaction of oil abundance and oil intensity in column 3 is highly significant but only marginally affects γ_1. Moving to the smaller sample of countries where measures of human capital are available, columns 4 to 6 show that the estimate of γ_1 is unaffected by the inclusion of controls for the skill and capital interactions. Finally, columns 7 to 9 show that γ_1 estimates are also similar when including controls for the legal institutions and fertile land per capita interactions.

The estimated coefficient on the ventilation and pollution interaction ($V_c \times e_i$) reported in column 9, where all controls are included, implies that when we move from a country at the mean ventilation coefficient to a country at one standard deviation above the mean, the predicted relative import share in an industry that is one standard deviation above the mean pollution intensity is 5.3% of a standard deviation higher relative to the import share in the industry with the mean pollution intensity. The beta coefficients of other sources of comparative advantage are of a similar size, from 7.6% for the oil interaction to 4.2% for the capital interaction.

4.2.2 2SLS estimates

In this section we report our two-stage least squares estimates of the effect of air pollution regulation on comparative advantage in polluting industries. As a reminder, we use the interaction of the ventilation coefficient in country c and pollution intensity in industry i ($V_c \times e_i$) as an instrument for the interaction of environmental regulation in country c and pollution intensity in industry i ($E_c \times e_i$) in equation (17). We start by describing the estimation of the first stage regression described by the following equation:

$$E_c \times e_i = \delta_1 \; V_c \times e_i + \delta_2 \; Y_c \times e_i + \delta_3 \; K_c \times k_i + \delta_4 \; H_c \times h_i + \theta_c + \theta_i + \nu_{ic}, \tag{20}$$

where the dependent variable is the interaction of environmental regulation in country c and pollution intensity in industry i ($E_c \times e_i$) and our excluded instrument is the interaction of the ventilation coefficient in country c and pollution intensity in industry i ($V_c \times e_i$). Recall that in our theoretical model, environmental regulation is a function of the ventilation coefficient (Result 2) and the country's level of technology (Result 3). In an effort to proxy for the latter we control for an interaction of GDP per capita (Y_c) and pollution intensity. In addition, we include the classical determinants of comparative advantage as controls as they belong to the second stage equation.

The estimation of the first-stage regression described in equation (20) is reported in Table 10. The first column includes only the interaction of the ventilation coefficient and pollution intensity ($V_c \times e_i$) as a regressor, and the rest of the columns add the remaining controls sequentially. The estimated coefficient on $V_c \times e_i$ is positive, stable and statistically significant at 1% in all specifications. The F-test on the excluded instrument ($V_c \times e_i$) varies between a value of 152 in column 1 where no controls are included, 93 in column 5 when only controls for capital and skill interactions are included, and 126 in the last column where all controls are included. Thus, it is unlikely that our second stage estimates will be biased by weak instruments. Note that the magnitude of our first stage estimates of the effect of the ventilation coefficient on environmental regulation is the same that we obtained when regressing country-level regulation on country-level ventilation coefficients, that is E_c on V_c, as reported in Table 5. In particular, the estimates in the first column of Tables 5 and 10 where no controls are included, are identical and have the same interpretation: if a country moves from the mean to a one standard deviation above the mean ventilation coefficient, the laxity of environmental regulation increases by 22% of a standard deviation.

Two-stage least squares estimates of equation (17) are reported in Table 11.[52] The first column includes only the (instrumented) interaction between environmental regulation and pollution intensity ($E_c \times e_i$) and the rest of the columns add the remaining controls sequentially. The estimated coefficient on the instrumented $E_c \times e_i$ 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 ($E_c \times e_i$) reported in column 4, where controls for per capita GDP, 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 stringency, 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 relative to the import share of the mean pollution intensity industry.

To assess the magnitude of the effect of environmental regulation on market shares implied by

---

[52] As in previous sections, we report standardized beta coefficients and robust standard errors in all baseline tables. In Appendix D, we show that coefficient estimates reported in Tables 10 and 11 remain precisely estimated when clustering standard errors across countries or across countries and industries (see tables D4 and D5 and D9 and D10, respectively). Further, in tables D14 and D15 we show that we obtain similar estimates when using the log of imports instead of the import market share as our dependent variable.

our estimates, we perform a quantification equivalent to the one presented above for OLS estimates. We use the sample median to divide countries into lax versus strict air pollution regulation. Similarly, we group industries into those that are more pollution intensive than the median and those that are not. Now consider taking the average lax air pollution regulation country and enacting a reform such that the policy stance would be that of the average strict regulation country. What would happen to its market share in the average polluting industry relative to the average non-polluting industry? Our 2SLS estimates imply that the difference in market shares would decrease by 0.20 percentage points.

Our baseline 2SLS estimates of the effect of environmental regulation on comparative advantage in polluting industries are around 80% higher than OLS estimates. To see this, note that OLS estimation of our baseline equation reported in column 4 of Table 11 is reported in column 4 of Table 8, where β_1 is 0.108. The finding that the 2SLS estimates exceed OLS estimates suggests that reverse causality and measurement error were generating a downwards bias in OLS estimates. As discussed above, reverse causality can downwards bias the estimated effect of environmental regulation if comparative advantage in polluting industries results in higher levels of pollution, which in turn induces the population to demand more stringent air pollution regulations. In particular, some advanced countries that industrialized earlier might have faced stronger demand from their citizens to address air pollution problems. If these countries tend to export more in polluting industries and have more stringent regulation, OLS estimates can be downwards biased. An additional source of downwards bias in OLS estimates is measurement error. Recall that our measure of environmental regulation, while easily comparable across countries, is limited to one dimension of air pollution regulation and is thus at best partial and subject to measurement error.

Taken together, 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 pollution concentration and the demand for air pollution policy. These estimates suggest that the effect of environmental regulation on comparative advantage is likely causal and comparable in magnitude to classical determinants of comparative advantage such as capital and skill abundance.

5 Conclusion

The traditional view in the trade and environment literature has held that the effects of environmental regulation on comparative advantage in polluting industries are small and unimportant relative to traditional determinants of comparative advantage. This conclusion stands at odds with ongoing policy debates and regulatory measures that seem premised on the existence of a significant pollution haven effect. Further, it conflicts with a large body of evidence documenting a sizeable effect of environmental regulation on intranational plant location.

The empirical results presented in this paper question the traditional view. In a standard cross-country, cross-industry test of comparative advantage, we show that the stance of environmental regulation is a statistically and economically significant determinant of comparative advantage in polluting industries. We find the magnitude of this effect to be comparable to the effect of other traditional determinants of comparative advantage.

Further, the extant literature has stressed the likely endogeneity of environmental regulation. We address this problem by acknowledging the importance of meteorological factors in shaping pollution concentration outcomes and, as a result, policy stringency. In particular, by turning to the literature on the determinants of atmospheric pollution dispersion we have identified a meteorological variable - the ventilation coefficient - that has a strong effect on environmental policy stringency and is uncorrelated with other determinants of comparative advantage. Using the ventilation coefficient as an instrument for air pollution regulation stringency, we show that the effect of the latter on comparative advantage is not only economically significant but likely causal.

Our results also suggest a number of directions for future research. First, an analysis of a broader set of pollutants is warranted. While we have focused on three standard criteria air pollutants, it is possible to construct industry-level measures of pollution intensity for other pollutants as well. In addition, given the current debates on the extent of CO2 leakage, our empirical framework can be of use in determining whether stricter regulation of greenhouse gases in some countries has lead CO2-intensive industries to relocate to countries with laxer CO2 regulations.

Finally, our instrumental variables strategy can be applied to intranational settings. For example, the literature studying the effect of air pollution regulation within the U.S. has stressed that a county's attainment status is determined by both industrial location and weather conditions affecting pollution concentration (see for example Greenstone [2002] and List et al. [2003]). Thus, our instrument, the ventilation coefficient, can be used to identify exogenous variation in attainment status across counties.

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] Angrist, J. D., and A. B. Krueger, (1999). "Empirical Strategies in Labor Economics," in Handbook of Labor Economics. , ed. Orley Ashenfelter and David Card, 1277–1366. Elsevier.

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

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

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

[6] Arya, S. P., (1998). *Air Pollution Meteorology and Dispersion,* New York: Oxford University Press.

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

[8] Barro, R. J. and J.-W. Lee, (2010). "A New Data Set of Educational Attainment in the World, 1950-2010," *NBER Working Paper* 15902.

[9] Bartelsman, E. J. and W. Gray, (1996). "The NBER Manufacturing Productivity Database." *NBER Technical Working Paper* 205.

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

[11] Cameron, C., J. Gelbach and D. Miller (2008). "Bootstrap-Based Improvements for Inference with Clustered Errors," *Review of Economics and Statistics* 90, 414-427.

[12] Caselli, F., (2005). "Accounting for Cross-Country Income Differences," in *Handbook of Economic Growth*, P. Aghion and S. H. Durlauf eds., Elsevier, 679-741.

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

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

[15] 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..

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

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

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

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

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

[21] Cuñat, A., and M. Melitz, (2012). "Volatility, Labor Market Flexibility, and the Pattern of Comparative Advantage," *Journal of the European Economic Association,* 10, 225-254.

[22] 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.

[23] 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.

[24] 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.

[25] Dean, J. M. and M. E. Lovely, (2010). "Trade Growth, Production Fragmentation, And China's Environment," *NBER Working Paper* 13860.

[26] Dee, D. P., S. M. Uppala, A. J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, M. A. Balmaseda, G. Balsamo, P. Bauer, P. Bechtold, A. C. M. Beljaars, L. van de Berg, J. Bidlot,

N. Bormann, C. Delsol, R. Dragani, M. Fuentes, A. J. Geer, L. Haimberger, S. B. Healy, H. Hersbach, E. V. Hólm, L. Isaksen, P. Kållberg, M. Köhler, M. Matricardi, A. P. McNally, B. M. Monge-Sanz, J.-J. Morcrette, B.-K. Park, C. Peubey, P. de Rosnay, C. Tavolato, J.-N. Thépaut, F. Vitart, (2011). "The ERA-Interim Reanalysis: Configuration and Performance of the Data Assimilation System," *Quarterly Journal of the Royal Meteorological Society* 137, 553-97.

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

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

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

[31] European Court of Justice, (1991). "Judgement of the Court of 11 June 1991: Commission of the European Communities v Council of the European Communities." Case C-300/89.

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

[33] Gassmann, M. I. and N. A. Mazzeo (2000). "Air Pollution Potential: Regional Study in Argentina," *Environmental Management*, 25, 375-382.

[34] Gellert, W., S. Gottwald, M. Hellwich, H. Kastner, and H. Kustner (1977). *The VNR Concise Encyclopedia of Mathematics*, Van Nostrand Reinhold, New York.

[35] 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.

[36] 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.

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

[38] 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.

[39] Hanna, R., (2010). “U.S. Environmental Regulation and FDI: Evidence from a Panel of U.S.-Based Multinational Firms” *American Economic Journal: Applied Economics* 2, 158-89.

[40] Henderson, V., (1996). “Effects of Air Quality Regulation,” *American Economic Review* 86, 789-813.

[41] Heston, A., R. Summers and B. Aten, (2009). *Penn World Table Version 6.3*, Center for International Comparisons of Production, Income and Prices, University of Pennsylvania.

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

[43] Hilton, F., and A. Levinson, (1998). “Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions,” *Journal of Environmental Economics and Management* 35, 126-41.

[44] Jacobson, M., (2002). *Atmospheric Pollution: History, Science and Regulation*, Cambridge University Press.

[45] Kalt, J. P., (1988). “The Impact of Domestic Environmental Regulatory Policies on U.S. International Competitiveness,” in *International Competitiveness.* A. Michael Spence and Heather A. Hazard, eds. Cambridge, MA: Harper and Row, Ballinger, 221–62.

[46] Kellenberg, D. (2009). “An Empirical Investigation of the Pollution Haven Effect with Strategic Environment and Trade Policy,” *Journal of International Economics* 78, 242-55.

[47] 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.

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

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

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

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

[52] 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.

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

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

[55] Lu, X., M. McElroy, and J. Kiviluoma, (2009). "Global Potential for Wind-Generated Electricity," *Proceedings of the National Academies of Sciences* 106, 10933-8.

[56] 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.

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

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

[59] Middleton, D., (1998). "A New Box Model to Forecast Urban Air Quality: BOXURB," *Environmental Monitoring and Assessment* 52, 315-35.

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

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

[62] Nunn, N. and D. Puga (2012), "Ruggedness: The Blessing of Bad Geography in Africa," *The Review of Economics and Statistics*, 94, 20-36.

[63] Ozer-Balli, H. and B. E. Sorensen (forthcoming). "Interaction Effects in Econometrics," *Empirical Economics.* forthcoming.

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

[65] Rauch, J. E., (1999). “Networks versus Markets in International Trade,” *Journal of International Economics*, 48, 7-35.

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

[67] Vittal Murty, K., D. Viswanadham, and Y. Sadhuram, (1980). “Mixing Heights and Ventilation Coefficients for Urban Centres in India,” *Boundary-Layer Meteorology* 19, 441-51.

[68] 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.

[69] Wagner, U. and C. Timmins, (2009). “Agglomeration Effects in Foreign Direct Investment and the Pollution Haven Hypothesis,” *Environmental and Resource Economics* 43, 231-56.

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

Appendix A: Proof of Result 2

Taking the derivative of Equation (13) with respect to A_j and rearranging we obtain

$$\frac{d\bar{E}_j^*}{dA_j} = P_d \cdot A_j^{\gamma-1} \cdot \frac{\left(P_c \cdot A \cdot L + \gamma \cdot P_d \cdot A \cdot \bar{E}_j^*\right) \cdot U''\left(I_j\left(\bar{E}_j^*\right)\right) + \gamma \cdot U'\left(I_j\left(\bar{E}_j^*\right)\right)}{V_j^{-2} \cdot W''\left(V_j^{-1} \cdot \bar{E}_j^*\right) - P_d^2 \cdot A_j^{2\cdot\gamma} \cdot U''\left(I_j\left(\bar{E}_j^*\right)\right)}.$$

The denominator is positive because $W'' > 0$ 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 $\gamma < 1$, $U'' < 0$, and $U' > 0$, the numerator is smaller than

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

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

Appendix B: The Box model

The model determines the concentration of pollutants within the box $\{(x, y, z) : x \in [0, \mathcal{L}], y \in [0, \mathcal{L}], z \in [0, h]\}$. 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

$$\frac{d}{dt}\int_0^x \int_0^y \rho\left(x', y', t\right) \cdot h \cdot dy' \cdot dx' = x \cdot y \cdot E - \int_0^x \rho\left(x', y, t\right) \cdot u \cdot h \cdot dx', \tag{21}$$

where h is mixing height, u is wind speed, and E is emissions per unit area. The first term on the right hand side is the pollution emitted 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

$$\int_0^x \rho\left(x', y\right) \cdot dx' = x \cdot y \cdot \frac{E}{u \cdot h}, \tag{22}$$

where we have omitted the time dependence. Taking the derivative of Equation (22) with respect to x we find

$$\rho\left(x,y\right) = y \cdot \frac{E}{u \cdot h}. \tag{23}$$

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

$$Z = \frac{1}{\mathcal{L}^2} \cdot \int_0^{\mathcal{L}} \int_0^{\mathcal{L}} \rho\left(x,y\right) \cdot dy \cdot dx. \tag{24}$$

Given Equation (23), this implies

$$Z = \frac{\mathcal{L}}{2} \cdot \frac{E}{u \cdot h}. \tag{25}$$

Appendix C: Data description

U.S. imports. Data on the value of U.S. imports refer to 2005 and come from Feenstra, Romalis and Schott (2002), updated to 2006. The original variable *gvalue* is the value in dollars paid for all U.S. general imports without consideration of import duties, freight and insurance charges. The data set comes with a 10-digits Harmonized Tariff System (HTS) product breakdown and has been aggregated to 4-digits NAICS sectors using the correspondence from 10-digits HTS to 6-digits NAICS provided by Feenstra, Romalis and Schott (2002). The dependent variable used in the regressions, country c's relative import shares into the U.S. (M_{ic}), is defined as country c's trade share in sector i divided by the average share of country c in U.S. imports. In all regressions we winsorize top and bottom 1% of observations in (M_{ic}) to reduce the importance of extreme values in our estimates. All results presented in the paper are robust to winsorizing M_{ic} at the 2.5% level.

Air pollution regulation. Our measure of air pollution regulation is maximum lead content (in grams) per liter of gasoline in 1996 multiplied by the market share of leaded gasoline. Note that the variable is defined in such a way that higher values indicate laxer air pollution regulation.

Both maximum lead content and market share of leaded gasoline are collected by the World Bank (Lovei, 1998) which has integrated data sourced from the main commercial producer of ethyl lead (Associated Octel Ltd.), with a number of industry publications, World Bank direct sources and personal contacts with government officials. The market share of leaded gasoline is equal to 1 minus the market share of unleaded gasoline and it is expressed in percentage points. For most countries (89) the information refers to 1996, but for 12 countries the variable is observed between 1992 and 1995.

Air pollution intensity. Pollution intensity at industry level is drawn from data compiled by the U.S. Environmental Protection Agency's (EPA) for their Trade and Environmental Assessment Model (TEAM), and it is based on EPA's 2002 National Emissions Inventory. Original data for Carbon Monoxide (CO), Nitrogen Oxides (NOx) and Sulfur Dioxide (SO2) emissions is defined as tons of pollutant emitted by 4-digits NAICS industries in 2002 and we divided it by total value of sales as given by TEAM. The variable used in all regressions is the log transformation of this measure expressed in tons of emissions per millions of dollars of value added. We correct and normalize these variables by multiplying factor emissions from TEAM by the value of shipments from the CES NBER Productivity Database, and then dividing the result with NBER's value added. The procedure is intended to bridge some discrepancies between the value of sales as reported by TEAM and by NBER.

The variable pollution intensity used in most regressions (e_i) is the simple average across the logarithms of pollution intensities of the three pollutants we focus on (CO, NOx and SO2). We also considered averaging across the logarithms of the standardized pollution intensities. The correlation between our baseline measure of pollution intensity and this alternative is 1.

Ventilation coefficient. We construct our own ventilation coefficient measure with wind speed and mixing height data from the ERA Interim, Synoptic Monthly Means, Full Resolution data set (Dee et al. 2011) provided by the European Centre for Medium-Term Weather Forecasting (ECMWF)[53]. This data set combines historical observational data with ECMWF's global forecasting model to construct a set of high quality weather variables on a global grid of $0.75° \times 0.75°$ cells (roughly 83 square kilometers).

Raw data used for the reanalysis rely on satellite observations, and are supplemented with records coming from radiosondes, pilot balloons, aircrafts, wind profilers as well as ships, drifting buoys and land weather stations' measurements. The result of ECMWF's meteorological reanalysis is a complete global grid that reports, for every month between January 1980 and December 2010, the monthly average for wind speed at 10 meters above the ground (in meters per second) and mixing height[54] (in meters) at noon. In order to construct our ventilation coefficient over the whole grid, we first multiply wind speed and mixing height in every month in the sample. Next, we compute for this new variable the 12 monthly averages over the past 30 years. Finally, we take the average across these 12 monthly means. The method intends to eliminate seasonal fluctuations and produces a measure that reflects long-term meteorological characteristics only.

In order to aggregate grid data at national level, we select the grid cell whose center is closest to the capital city of every country, and assign the ventilation coefficient of that cell to the whole

---

[53] Accessible at: http://data-portal.ecmwf.int/data/d/interim_full_mnth/

[54] ERA-Interim refers to mixing height as "boundary layer height".

country. The data set of coordinates for capital cities around the world is constructed from several web sources. The main reference is the Nation Master website[55] but virtually all data points have been double checked with other online sources.

Given the latitude and the longitude of a city (lat_c and long_c) and of the coordinates of the center of a grid cell (lat_g and long_g) expressed in decimal values, distance between the city and the cell is approximated using the spherical law of cosines (Gellert et al., 1989, p. 262):

$$d(c,g) = \text{acos}\Bigg[\sin\left(\frac{lat_c}{180}\pi\right)\sin\left(\frac{lat_g}{180}\pi\right) + \cos\left(\frac{lat_c}{180}\pi\right)\cos\left(\frac{lat_g}{180}\pi\right)\cos\left(\left(\frac{long_g}{180}\pi\right) - \left(\frac{long_c}{180}\pi\right)\right)\Bigg] \times 6378.137$$

where the last number is the radius of the Equator in kilometers. Note that, although the formula assumes that the Earth is a perfect sphere, the inaccuracy resulting from this assumption is irrelevant for our purposes since we use these distances only to assess the relative position of different grid cells with respect to every city in the sample.

Stock of physical Capital. Capital endowment (K_c) is defined as the logarithm of capital per worker in 2002 and it is computed with data sourced from Penn World Table 6.3 (PWT: Heston, Summers and Aten, 2009) following the *Perpetual Inventory Method* suggested by Caselli (2005, p.685).

Total real capital endowment in year t is calculated as: $K_t = I_t + (1-\delta)K_{t-1}$. Investment in year t I_t is computed as investment share in total income (variable *ki* in the PWT data set) times real GDP per capita at constant 2005 Laspeyres price (*rgdpl*) times population: $I_t = rgdpl_t \times (pop_t \times 1000) \times (ki_t/100)$; δ is the rate of depreciation of capital and it is set equal to 0.06. K_{t-1} is the real value of capital in the previous year. We assume that when a country enters the data set it is in its long-run steady state: accordingly set $K_0 = I_0/(\delta + g)$ where g is average geometric growth rate for investment for the first 20 years of observation in the data set. The variable capital per worker is obtained by dividing total real capital by the number of workers in 2002. The number of workers in that year, is in turn calculated as real GDP per capita at constant price (*rgdpch*) times total population divided by real GDP per worker (*rgdpwok*). In all regressions we discard all 36 countries whose stock of real capital in 2002 was calculated with less than 33 years of observations.

Stock of human capital. Our measure of human capital (H_c) is computed applying the method proposed by Hall and Jones (1999) to the data organized by Barro and Lee (2010). The variable used is the average years of education in 2000 for the population above 25 years (*tyr99*

---

[55] Accessible at: http://www.nationmaster.com.

in the original data set). As Hall and Jones we assume: $H_c = \exp(\varphi(tyr99))$ where $\varphi(\cdot)$ is a step function defined as:

$$\begin{array}{rlll}
\varphi(tyr99) = & 0.134 \cdot tyr99 & \text{if} & tyr99 \leqslant 4 \\
\varphi(tyr99) = & 0.134 \cdot 4 + 0.101 \cdot (tyr99 - 4) & \text{if} & 4 < tyr99 \leqslant 8 \\
\varphi(tyr99) = & 0.134 \cdot 4 + 0.101 \cdot 8 + 0.068 \cdot (tyr99 - 8) & \text{if} & 8 < tyr99.
\end{array}$$

In the regressions we use the logarithm of H_c.

Capital and skill intensity. Our measures of capital and skill intensity are drawn from Bartelsman and Gray (1996) NBER-CES Manufacturing Industry Database and refer to 2002. Since original data come at the 6-digits NAICS level: we aggregate them at the 4-digits level before computing factor intensities.

Capital intensity in every 4-digits NAICS industry (k_i) is equal to real capital stock in 2002 (*cap*, originally expressed in millions of 1987 dollars) divided by value added in the same year (*vadd*, in millions of dollars).

Skill intensity in 2002 (h_i) is computed as 1 minus the share of wages to production workers on total payroll from the variables *prodw* (total amount of wages to production workers, in millions of dollars) and *pay* (total payroll, also in millions of dollars) within 4-digits NAICS industries.

Income per capita. Our measure of income per capita is the logarithm of real gross domestic product per capita in U.S. dollars at PPP current prices in 2002 from the PWT database (variable *cgdp*).

TFP growth. Total factor productivity (TFP) growth is computed from variable *tfp5* in Bartelsman and Gray (1996) and it is defined as 1 plus the growth rate in TFP over the period 1997-2002. Original data are classified according to 6-digits NAICS codes: TFP growth for 4-digits NAICS sectors is the weighted average of 6-digits industries TFP growth within the wider category.

Value of sales and value added. The measures of value of sales and value added in 4-digits U.S. NAICS industries mentioned at various points in the paper are both from Bartelsman and Gray (1996) NBER-CES Manufacturing Industry Database. We aggregated the original 6-digits NAICS industries variables in 2002 at 4-digits level. Value of sales (*vship*) is value of industry shipments in millions of dollars. Value added (*vadd*) is defined as total value of industry shipments minus the cost of materials, plus the change in finished goods, in work-in-process and in inventories during the year. It is also expressed in millions of dollars. The variable "value added" (VA_i) used in all regressions is defined as *vadd* divided by *vship*.

Oil abundance. Our measure of oil abundance is proven reserves of crude oil (in billions of barrels) in 2003 divided by 2002 population. Oil reserves are sourced from the U.S. Energy Information Administration's International Energy Statistics, available at `http://www.eia.gov`. Population information for the year 2002 is from PWT.

Oil intensity. We approximate oil intensity in 4-digits NAICS sector with oil and gas use over total output (both expressed in millions of dollars and at producer prices) from 2002 U.S. Input-Output tables[56]. Original I-O sectors are matched to 4-digits NAICS industries manually, with the table of concordance provided by BEA.

Contract intensity. The measure of contract intensity at 4-digits NAICS industry is computed by Nunn (2007) for the U.S. in 1997. The variable we use here corresponds to z_i^{rs1} in Nunn's paper (and to *frac_ lib_ diff* in Nunn's (2007) online database): it is defined as the fraction of inputs used by industry i that are neither traded on exchanges nor are referenced priced on trade publications. See Nunn (2007, pp. 575-577) for details on how the variable is built from U.S. I-O matrix and Rauch (1999) product pricing classification.

Efficiency of legal institutions. Our measure of efficiency of legal institutions is *num_ proc*: 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 in 2003. The variable comes from the database organized by Nunn (2007) and it is defined in the same manner, i.e. as 60 minus the total number of procedures. Note that under this definition a higher value of this variable indicates higher quality of the judicial system. See Nunn (2007) for details on how the variable was derived from World Bank data.

Fertile land per capita. We define fertile land per capita as hundreds of hectares per capita in 2002. The variable is drawn from data assembled by Nunn and Puga (2012) and population data from PWT as: land area in thousands of hectares times percentage of fertile soil (respectively *land_ area* and *soil* in Nunn and Puga (2012)) divided by total population in 2002 from PWT (*pop*, in thousands of people). Percentage of fertile soil is defined as the percentage of land surface area of each country whose soil is not subject to severe constraints for growing rainfed crops. See Nunn and Puga (2012) for details and references to original sources.

---

[56] The exact name of the table is "The Use of Commodities by Industries after Redefinitions, 2002 Benchmark" and it is available on the BEA website: `www.bea.gov`.

Table C1

Summary Statistics

PANEL A: Dependent Variable

Full Sample

Variable Name	Definition	Mean	St. Dev.	Obs.
Relative Import Share	Country c's share of U.S. imports in industry i relative to its average share	0.65	1.84	8585
Average Import Share	Country c's average share in U.S. imports	0.01	0.03	101

Sample with data on human capital

Variable Name	Definition	Mean	St. Dev.	Obs.
Relative Import Share	Country c's share of U.S. imports in industry i relative to its average share	0.72	1.85	6205
Average Import Share	Country c's average share in U.S. imports	0.01	0.03	73

PANEL B: Industry-level variables

Variable Name	Definition	Mean	St. Dev.	Obs.
NOx Intensity	Tons of NOx emitted per 2002 dollar of value added	1.51	2.17	85
SO2 Intensity	Tons of SO2 emitted per 2002 dollar of value added	1.60	2.93	85
CO Intensity	Tons of CO emitted per 2002 dollar of value added	3.54	5.62	85
Pollution Intensity	Average of NOx, SO2 and CO Intensity	2.22	3.17	85
Skill intensity	Share of wage bill to non-production workers	0.39	0.12	85
Capital Intensity	Capital over value added	1.14	0.59	85
TFP growth	1+ total factor productivity growth between 1997 and 2002	0.96	0.21	85
VA	Value added over total value of shipments	0.50	0.11	85
Contract Intensity	Share of inputs not traded on organized exchanges nor reference priced	0.51	0.21	85
Oil Intensity	Expenditure on oil and gas per dollar of gross output	0.01	0.06	85

Table C1 (continued)

Summary Statistics

PANEL C: Country-level variables

Full Sample

Variable Name	Definition	Mean	St. Dev.	Obs.
Lax Air Pollution Regulation	Average lead content of gasoline (grams/liter)	0.36	0.30	101
Ventilation Potential	Average wind speed × mixing height (square meters/second)	4046.66	2883.22	101
Income per capita	Real GDP per capita in 2002 dollars	11074.13	10464.20	101

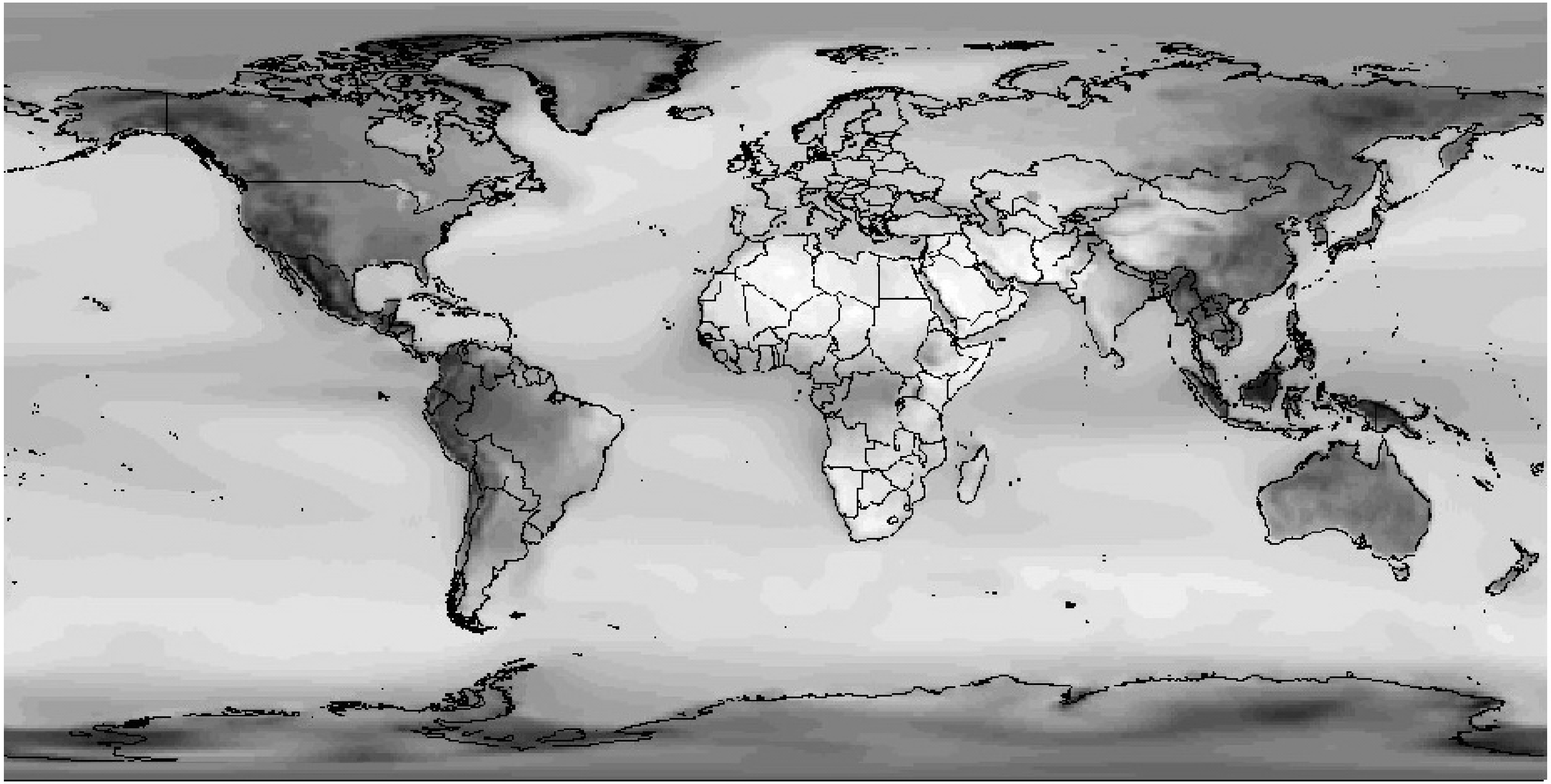
Sample with data on human capital

Variable Name	Definition	Mean	St. Dev.	Obs.
Lax Air Pollution Regulation	Average lead content of gasoline (grams/liter)	0.30	0.29	73
Ventilation Potential	Average wind speed × mixing height (square meters/second)	3764.82	2866.17	73
Income per capita	Real GDP per capita in 2002 dollars	12450.28	10798.99	73
Skill Abundance	Log of efficiency of average worker over a worker with no education	0.76	0.27	73
Capital Abundance	Real capital per worker	86067.83	83700.97	73
Fertile Land per capita	Hundreds of hectares per capita	79.62	106.65	73
Oil Abundance	Proven reserves (millions of barrels) per capita	0.89	5.40	73
Efficiency of Legal Institutions	60 - number of procedures required to collect an overdue debt	30.99	11.72	68

Note: industries are 4-digits NAICS manufacturing sectors; countries considered are all countries with population of at least half a million. Refer to Data Appendix for further details on the variables.

Figure 1

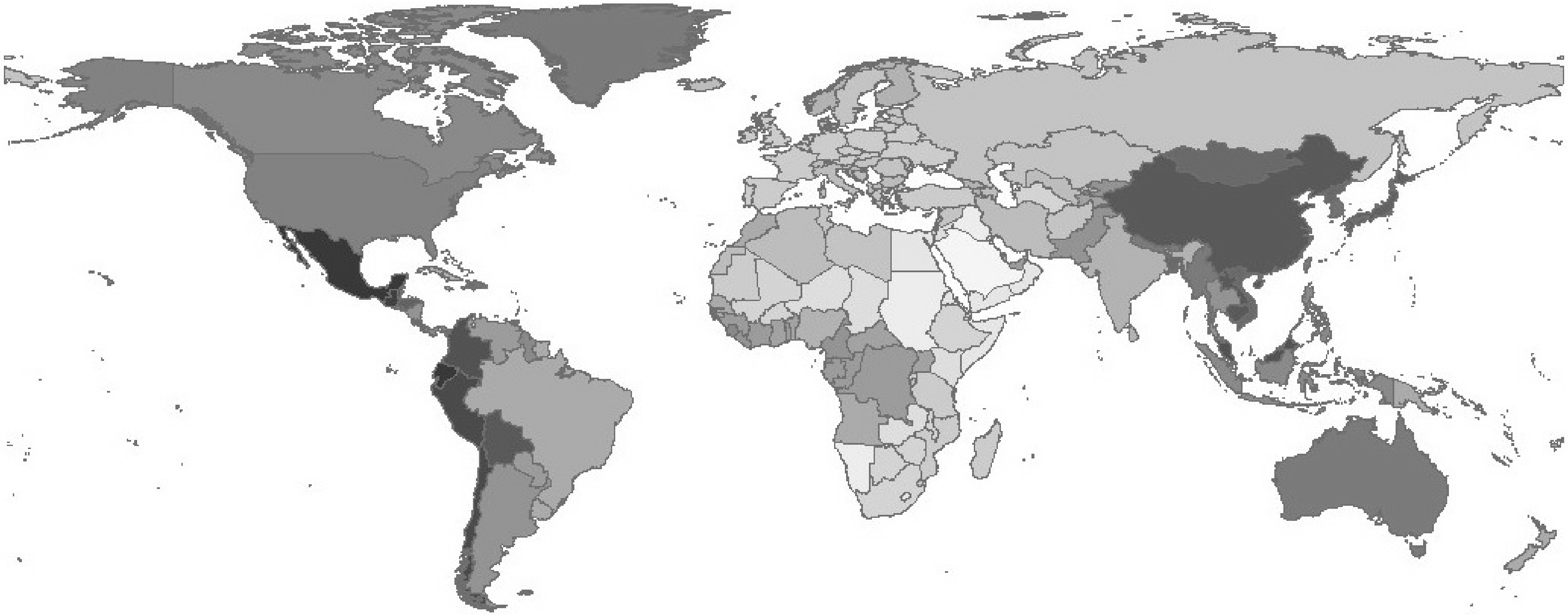
Ventilation Coefficient



Note: 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 $0.75^o \times 0.75^o$ cells we then average over all months and take logs. Darker (lighter) areas correspond to lower (higher) ventilation coefficients.

Figure 2

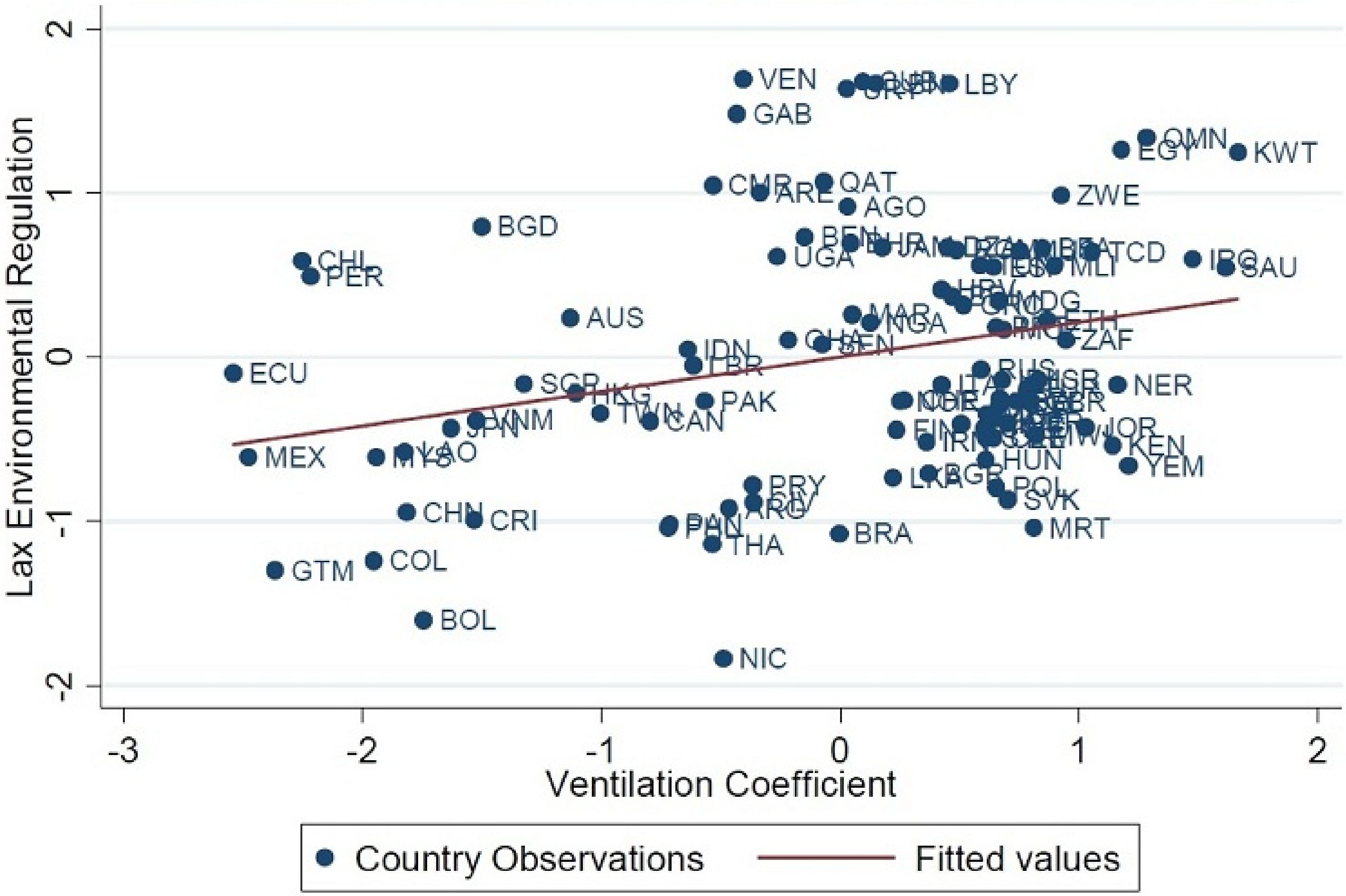
Country-level Ventilation Coefficient



Note: 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 $0.75^o \times 0.75^o$ 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.

Figure 3

Ventilation Coefficient and Environmental Regulation



Note: The relationship between environmental regulation (E_c) on the ventilation coefficient (V_c). Country names are included. Fitted values correspond to the regression reported in column 2 of Table 5, where GDP per capita is included as a control.

Table 1

Ten most pollution intensive manufacturing industries for each pollutant.

	NOx		SO2		CO	
Rank	Industry	EF	Industry	EF	Industry	EF
1	Lime and gypsum	13.6	Petroleum and Coal Products	13.7	Alumina and aluminum	43.2
2	Cement and concrete	9.92	Nonferrous Metal(not Aluminum)	13.0	Iron/Steel Mills and Ferroalloy	20.6
3	Petroleum and Coal Products	8.46	Alumina and Aluminum	12.7	Petroleum and Coal Products	15.8
4	Pulp/paper/paperboard mills	6.71	Lime and gypsum	9.86	Lime and Gypsum	14.4
5	Glass and glass products	6.52	Pulp/paper/paperboard mills	9.44	Steel Products Other	12.3
6	Basic Chemicals	4.80	Cement and concrete	7.72	Basic Chemicals	10.7
7	Pesticide and fertilizer	4.67	Pesticide and fertilizer	6.68	Pulp/paper/paperboard mills	10.2
8	Veneer/Plywood/Eng. Wood	2.97	Basic Chemicals	6.60	Nonferrous Metal(not Alum.)	8.99
9	Iron/Steel Mills and Ferroalloy	2.94	Grain/Oilseed Milling	4.59	Veneer/Plywood/Eng.Wood	8.19
10	Grain/Oilseed Milling	2.73	Other Chemicals	3.71	Cement and Concrete	8.13

Note: Emission factors (EF) are defined as tons of pollutant emitted per million dollars of value added.

Table 2

Rank correlation of industry-level pollution intensity across different pollutants.

	NOx	SO2	CO
NOx	1	-	-
SO2	0.91***	1	-
CO	0.93***	0.88***	1

Note: Table reports Spearman's rank correlation coefficient.

*** indicates significance at the 1 percent level.

Table 3

Correlation between industry-level pollution, skill and capital intensities.

	NOx	SO2	CO
Skill Intensity	-0.37***	-0.33***	-0.36***
Capital Intensity	0.59***	0.61***	0.61***

Note: *** indicates significance at the 1 percent 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

Table 5

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***
	(0.082)	(0.069)	(0.069)	(0.069)	(0.069)	(0.084)	(0.092)	(0.074)	(0.074)
Income per capita $_c$		-0.624***	-0.617***	-0.628***	-0.680***	-0.680***	-0.202	-0.659***	-0.564***
		(0.058)	(0.059)	(0.058)	(0.054)	(0.068)	(0.305)	(0.061)	(0.072)
Fertile Land per capita $_c$			0.063						
			(0.081)						
Oil Abundance $_c$					0.216***				
					(0.058)				
Skill Abundance $_c$							-0.351**		
							(0.153)		
Capital Abundance $_c$							-0.183		
							(0.281)		
Efficiency Legal Institutions $_c$									-0.246***
									(0.085)
Observations	101	101	101	99	99	73	73	89	89

Note: The dependent variable is the level of laxity of environmental regulation in country *c*. Standardized beta coefficients are reported, with robust standard errors in parenthesis. *** indicates significance at the 1 percent level, ** at the 5 percent and * at the 10 percent.

Table 6

Environmental Regulation and Comparative Advantage in Polluting Goods

Dependent variable: Import Share

	1	2	3	4
Lax Air Pollution Regulation $_c\times$ Pollution Intensity $_i$	0.062***			
	(0.013)			
Lax Air Pollution Regulation $_c\times$ NOx Intensity $_i$		0.054***		
		(0.012)		
Lax Air Pollution Regulation $_c\times$ SO2 Intensity $_i$			0.062***	
			(0.013)	
Lax Air Pollution Regulation $_c\times$ CO Intensity $_i$				0.062***
				(0.012)
Country fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	8,585	8,585	8,585	8,585

Note: The dependent variable is the relative import share of country c in industry i, M_{ic}. Standardized beta coefficients are reported, with robust standard errors in parenthesis. *** indicates significance at the 1 percent level, ** at the 5 percent and * at the 10 percent.

Table 7

Environmental Regulation and Comparative Advantage in Polluting Goods - Baseline OLS Estimates

Dependent variable: Import Share

	1	2	3	4	5	6	7
Lax Air Pollution Regulation $_c \times$ Pollution Intensity $_i$	0.078***	0.083***	0.083***	0.079***	0.088***	0.080***	0.075***
	(0.015)	(0.017)	(0.017)	(0.018)	(0.019)	(0.018)	(0.019)
Skill Abundance $_c \times$ Skill Intensity $_i$		0.066***	0.068***	0.062***	0.067***	0.063***	0.057***
		(0.012)	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)
Capital Abundance $_c \times$ Capital Intensity $_i$		0.051***	0.053***	0.060***	0.054***	0.058***	0.070***
		(0.014)	(0.015)	(0.014)	(0.015)	(0.015)	(0.015)
Income per capita $_c \times$ TFP growth $_i$			-0.009				
			(0.014)				
Income per capita $_c \times$ VA $_i$				0.024			0.036**
				(0.016)			(0.018)
Efficiency of Legal Institutions $_c \times$ Contract Intensity $_i$						0.043***	0.045***
						(0.015)	(0.016)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,205	6,205	6,205	6,205	5,780	5,780	5,780

Note: The regressions are estimates of equation (17). The dependent variable is the relative import share of country c in industry i, M_{ic}. Standardized beta coefficients are reported, with robust standard errors in parenthesis. *** indicates significance at the 1 percent level, ** at the 5 percent and * at the 10 percent.

Table 8

Environmental Regulation and Comparative Advantage in Polluting Goods - Robustness OLS Estimates

Dependent variable: Import Share

	1	2	3	4	5	6	7
Lax Air Pollution Regulation $_c\times$ Pollution Intensity $_i$	0.062***	0.097***	0.083***	0.108***	0.107***	0.098***	0.091***
	(0.013)	(0.018)	(0.017)	(0.023)	(0.023)	(0.022)	(0.022)
Income per capita $_c\times$ Pollution Intensity $_i$		0.055***		0.050**	0.051**	0.041*	0.033
		(0.019)		(0.023)	(0.023)	(0.021)	(0.022)
Skill Abundance $_c\times$ Skill Intensity $_i$			0.066***	0.070***	0.071***	0.070***	0.067***
			(0.012)	(0.012)	(0.012)	(0.012)	(0.013)
Capital Abundance $_c\times$ Capital Intensity $_i$			0.051***	0.033**	0.034**	0.034**	0.042***
			(0.014)	(0.014)	(0.014)	(0.014)	(0.015)
Fertile Land per capita $_c\times$ Pollution Intensity $_i$					0.030***	0.031***	0.030***
					(0.011)	(0.011)	(0.011)
Oil Abundance $_c\times$ Oil Intensity $_i$						0.085***	0.086***
						(0.006)	(0.007)
Efficiency of Legal Institutions $_c\times$ Contract Intensity $_i$							0.039***
							(0.015)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,585	8,585	6,205	6,205	6,205	6,205	5,780

Note: The regressions are estimates of equation (17). The dependent variable is the relative import share of country c in industry i, M_{ic}. Standardized beta coefficients are reported, with robust standard errors in parenthesis. *** indicates significance at the 1 percent level, ** at the 5 percent and * at the 10 percent.

Table 9

Ventilation Potential and Comparative Advantage in Polluting Goods - Reduced Form Estimates

Dependent variable: Import Share

	1	2	3	4	5	6	7	8	9
Ventilation Potential $_c\times$ Pollution Intensity $_i$	0.057***	0.057***	0.054***	0.045***	0.045***	0.046***	0.055***	0.049***	0.053***
	(0.010)	(0.010)	(0.009)	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)
Income per capita $_c\times$ Pollution Intensity $_i$		0.017*	0.013			-0.015	-0.019	-0.024	-0.022
		(0.010)	(0.010)			(0.014)	(0.016)	(0.015)	(0.015)
Oil Abundance $_c\times$ Oil Intensity $_i$			0.057***					0.076***	0.076***
			(0.020)					(0.007)	(0.007)
Skill Abundance $_c\times$ Skill Intensity $_i$					0.058***	0.056***	0.056***	0.055***	0.056***
					(0.011)	(0.011)	(0.012)	(0.012)	(0.012)
Capital Abundance $_c\times$ Capital Intensity $_i$					0.023**	0.031***	0.042***	0.042***	0.042***
					(0.011)	(0.012)	(0.013)	(0.013)	(0.013)
Efficiency of Legal Institutions $_c\times$ Contract Intensity $_i$							0.049***	0.043***	0.045***
							(0.014)	(0.013)	(0.013)
Fertile Land per capita $_c\times$ Pollution Intensity $_i$									0.039***
									(0.010)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,750	12,750	12,580	8,075	8,075	8,075	7,140	7,140	7,140

Note: The regressions are estimates of equation (19). The dependent variable is the relative import share of country c in industry i, M_{ic}. Standardized beta coefficients are reported, with robust standard errors in parenthesis. *** indicates significance at the 1 percent level, ** at the 5 percent and * at the 10 percent.

Table 10

Ventilation Potential and Environmental Regulation - First Stage Estimates

Dependent variable: Environmental Regulation $_c \times$ Pollution Intensity $_i$

	1	2	3	4	5	6	7	8	9
Ventilation Potential $_c \times$ Pollution Intensity $_i$	0.219***	0.211***	0.218***	0.217***	0.191***	0.201***	0.206***	0.203***	0.213***
	(0.018)	(0.015)	(0.018)	(0.018)	(0.020)	(0.019)	(0.019)	(0.019)	(0.019)
Income per capita $_c \times$ Pollution Intensity $_i$		-0.624***	-0.680***	-0.656***		-0.671***	-0.632***	-0.635***	-0.632***
		(0.013)	(0.015)	(0.017)		(0.016)	(0.019)	(0.019)	(0.019)
Skill Abundance $_c \times$ Skill Intensity $_i$				0.035***	0.135***		0.023***	0.023***	0.025***
				(0.007)	(0.011)		(0.007)	(0.007)	(0.007)
Capital Abundance $_c \times$ Capital Intensity $_i$				-0.022**	-0.387***		-0.015	-0.014	-0.013
				(0.011)	(0.016)		(0.012)	(0.012)	(0.012)
Efficiency of Legal Institutions $_c \times$ Contract Intensity $_i$							0.088***	0.085***	0.084***
							(0.015)	(0.015)	(0.015)
Oil Abundance $_c \times$ Oil Intensity $_i$								0.042***	0.042***
								(0.007)	(0.007)
Fertile Land per capita $_c \times$ Pollution Intensity $_i$									0.063***
									(0.022)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,585	8,585	6,205	6,205	6,205	5,780	5,780	5,780	5,780
F-test on excluded instrument	152.5	199.7	144.3	142.8	93.1	111.9	117.8	115.2	125.6

Note: The regressions are estimates of equation (20). The dependent variable is the interaction of environmental regulation in country c and pollution intensity in industry i ($E_c \times e_i$). Standardized beta coefficients are reported, with robust standard errors in parenthesis. *** indicates significance at the 1 percent level, ** at the 5 percent and * at the 10 percent.

Table 11

Environmental Regulation and Comparative Advantage in Polluting Goods

Two-Stage Least Squares Estimates

Dependent variable: Import Share

	1	2	3	4	5	6	7	8	9
Lax Air Pollution Regulation $_c \times$ Pollution Intensity $_i$	0.237***	0.246***	0.193***	0.186***	0.207***	0.231***	0.238***	0.213***	0.232***
	(0.057)	(0.058)	(0.062)	(0.063)	(0.071)	(0.072)	(0.072)	(0.069)	(0.066)
Income per capita $_c \times$ Pollution Intensity $_i$		0.149***	0.105**	0.100**		0.123**	0.129***	0.108**	0.122***
		(0.039)	(0.044)	(0.043)		(0.050)	(0.048)	(0.045)	(0.043)
Skill Abundance $_c \times$ Skill Intensity $_i$				0.067***	0.049***		0.062***	0.062***	0.063***
				(0.013)	(0.015)		(0.013)	(0.013)	(0.013)
Capital Abundance $_c \times$ Capital Intensity $_i$				0.035**	0.099***		0.044***	0.044***	0.045***
				(0.014)	(0.030)		(0.015)	(0.015)	(0.015)
Efficiency of Legal Institutions $_c \times$ Contract Intensity $_i$							0.035**	0.031**	0.029*
							(0.015)	(0.015)	(0.015)
Oil Abundance $_c \times$ Oil Intensity $_i$								0.078***	0.078***
								(0.008)	(0.008)
Fertile Land per capita $_c \times$ Pollution Intensity $_i$									0.025**
									(0.012)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,585	8,585	6,205	6,205	6,205	5,780	5,780	5,780	5,780

Note: The table reports 2SLS estimates of equation (17). The dependent variable is the relative import share of country c in industry i, M_{ic}. Standardized beta coefficients are reported, with robust standard errors in parenthesis. *** indicates significance at the 1 percent level, ** at the 5 percent and * at the 10 percent.