Sources of Comparative Advantage in Polluting Industries[*]

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Abstract

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.

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1 Introduction

Over the course of the last half-century the costs associated to environmental degradation have become increasingly apparent. The depletion of natural resources, the detrimental effects of pollution on human health and the uncertain prospects brought about by global climate change have become first-order issues for policy-makers and academics.

In an attempt to address these concerns many countries have adopted stricter environmental regulations. However, the stringency of regulation varies across countries, suggesting the possibility that environmental regulation affects the location of polluting industries. 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.

Determining the existence and strength of this source of comparative advantage, known as the *pollution haven effect*, is important for a number of ongoing policy-relevant discussions. First, the concentration of polluting activities in countries with lax regulation can impose substantial health costs on developing countries where recent studies document high local pollutant concentrations.[1] Second, the effectiveness of policies aimed at reducing global greenhouse gas emissions depends on their effects on the location of industrial activities across countries.[2] Third, the extent to which environmental regulation can be used as an instrument to carry out trade policy has been a recurrent issue in international trade negotiations.[3]

Despite the theoretical appeal and policy relevance of the pollution haven effect, there is still no consensus about its economic significance. Early empirical studies in the trade and the environment literature found this effect to be small and unimportant relative to traditional determinants of comparative advantage, such as capital abundance.[4,5] More recent studies attributed these results to mismeasurement and endogeneity of environmental regulation and proposed an instrumental variable approach.[6] However, this approach has not yet provided convincing evidence on the pollution haven effect due to the difficulties in finding valid instruments for environmental regulation.

In this paper, we combine data on environmental policy at the country level with data on pollution intensity at the industry level to implement the standard test of comparative advantage proposed by

[1] See Greenstone and Hanna (2011) for India, Hanna and Oliva (2011) for Mexico, and Chen et al. (2011) for China.

[2] For a discussion of the impact of these policies on trade flows, e.g. *carbon leakage,* see Babiker (2005) and Elliott et al. (2010). Relatedly, for analyses of the impact of climate change on international trade see Costinot et al (2012) and Desmet and Rossi-Hansberg (2013).

[3] The inclusion of specific clauses in NAFTA dissuading members from "encourag(ing) investment by relaxing [...] environmental measures" (Article 1114) is consistent with this concern.

[4] See Grossman and Krueger (1993), Antweiler et al. (2001), and, for a survey, Copeland and Taylor (2004).

[5] In contrast, there is ample evidence that environmental regulation affects the location of polluting industries *within* the U.S.. See Henderson (1996), Becker and Henderson (2000), Greenstone (2002), List et al. (2003), Hanna (2010), and Greenstone et al. (2012) for an evaluation of the effects of the Clean Air Act.

[6] See Ederington and Minier (2003) and Levinson and Taylor (2008). We review the literature in detail below.

Romalis (2004).[7] We find 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 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 the empirical work, we begin by presenting a simple model that analyzes the effects of environmental policy on the patterns of international trade. As is standard in the literature on trade and the environment, we treat pollution as another factor of production, whose relative supply is determined by environmental policy; see Copeland and Taylor (2003).[8] 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 Romalis (2004)'s cross-country, cross-industry methodology by incorporating environmental regulation as a determinant of comparative advantage in polluting industries. 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

[7] This test has been used to study a variety of sources of comparative advantage in the recent literature. See Levchenko (2007), Nunn (2007), Costinot (2009a), Chor (2010), Bombardini et al. (2012), Cuñat and Melitz (2012), and Manova (2012). See Nunn and Trefler (2013) for a review of this literature. Costinot (2009b) provides a general theoretical framework and derives sufficient conditions for the validity of this empirical test of comparative advantage.

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

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 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.[9] 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 - i.e. countries with high ventilation coefficient - the marginal cost of emissions is lower and, as a

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

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.[10]

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. 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.[11] 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.[12] Third, we analyze data from recent periods where trade with developing countries became more important. As a result of these differences, we reach opposite

[10] We check that the instrument is as good as randomly assigned by showing that countries with above median ventilation coefficient do not differ in terms of observables, other than environmental regulation, from countries with below median ventilation coefficient. See Table 1.

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

[12] The capital costs of complying with regulations are hard to measure because it is difficult to separate them from standard cost of capital. An example would be a situation in which a new facility needs to be built to comply with environmental regulations.

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 analyzed how more stringent environmental regulation following the Clean Air Act affected U.S. comparative advantage (Ederington and Minier, 2003, Ederington et al., 2005, and Levinson and Taylor, 2008). These studies exploit changes in PAC within industries to identify the effect of environmental regulation. Note that the interpretation of PAC in these studies differs from that in Grossman and Krueger (1993) who use differences in PAC across industries to measure pollution intensity. In contrast, the recent literature uses variation in PAC across time to measure industry-specific changes in environmental regulation stringency. The typical finding is that U.S. industries facing larger increases in PAC experienced either small or statistically insignificant increases in overall imports. Ederington et al. (2005) find larger estimates for imports coming from developing countries. However, the estimates are not statistically different for countries with lax and strong environmental regulation and are in fact smaller for more pollution-intensive industries. These puzzling results might be related to the use of PAC to measure both changes in environmental regulation and pollution intensity.[13]

In sum, the common finding of the recent literature is that OLS estimates of the effect of increases in PAC 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.

Several authors have attributed the weakness of OLS estimates to biases caused by mismeasurement and endogeneity of environmental regulation.[14] Indeed, recent studies found larger estimates of the effects of environmental regulation on trade flows when using instrumental variable strategies. However, this evidence has not settled the debate because the proposed instruments for environmental regulation require strong assumptions to satisfy the exogeneity and exclusion restrictions. For example, Ederington and Minier (2003) instrument for changes over time in U.S. industry-level environmental regulation with a set of variables that includes industry size. More recently, Levinson and Taylor (2008) have proposed to instrument industry-level changes in environmental regulation with changes in both income per capita and emissions in the states where the corresponding industry is located. Both sets of variables are likely to be endogenous to a variety of observables and unobservables, possibly including trade itself. In addition, it is hard to exclude the possibility that both sets of variables affect trade through channels other than environmental regulation. As examples, industry size can affect comparative advantage due to increasing returns to scale (Krugman, 1979), and income

[13] Copeland and Taylor (2004) point out a number of problems arising from the use of PAC as measures of pollution intensity and environmental regulation. For example, more stringent regulation can cause the more polluting activities within an industry to migrate to other countries. This compositional effect can generate a negative correlation between imports and changes in PAC.

[14] See the survey by Copeland and Taylor (2004).

per capita can affect comparative advantage due to home market effects (Krugman, 1980).

In this paper we propose an instrument for environmental regulation based on meteorological conditions identified by the atmospheric pollution science literature that can be used to establish the causal effects of environmental regulation on economic outcomes. This instrument can contribute to solve the identification problem stressed by the earlier literature because it is based on exogenous weather patterns and is not correlated with observable sources of comparative advantage other than environmental regulation, thus it is likely to meet the exclusion restriction.

Our work is also related to the literature studying the effect of environmental regulation on industrial activity within the U.S.. Henderson (1996), Becker and Henderson (2000), Greenstone (2002), and List et al. (2003) find that polluting industries have relocated to U.S. counties where environmental regulation is laxer.[15] 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.[16] 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.

The instrument we propose could also be of interest to this literature on plant location and environmental regulation. In particular, it could help isolate the sources of environmental policy variation across U.S. counties. As Greenstone (2002) notes, 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. While in this paper we only exploit cross-country variation in atmospheric conditions, our instrumentation strategy can potentially be applied to smaller geographical units in order to isolate the part of variation in environmental regulation across U.S. counties that is exogenously determined by weather conditions.

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 (2012) focuses on financial development and Levchenko (2007), Nunn (2007) and Costinot (2009a) focus on contract enforcement. Finally, Bombardini, Gallipoli and Pu-

[15] Greenstone et al. (2012) also find that TFP in polluting industries decreased in counties with stricter environmental regulation.

[16] 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).

pato (2012) study the effects of dispersion in the distribution of skills while 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 A simple model

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.

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.[17]

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

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

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.[18,19] 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.[20]

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

[18] 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).

[19] 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.

[20] 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.

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

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

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.[21] 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

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

[21] 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 $P_c^{\alpha_c} \cdot P_d^{\alpha_d} = \alpha_c^{\alpha_c} \cdot \alpha_d^{\alpha_d}$.

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:*

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

We now turn to the determination of emission limits. Country j chooses $\bar{E}_j$ to maximize its 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 specification 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 specification, 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.[22] 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 equation (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. For a detailed discussion of our empirical strategy refer to Section 4.

To implement the empirical specification described in equation (17) 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

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

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.[23] The data on U.S. imports refers to 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.[24,25]

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).[26] 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

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

[24] 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.

[25] Note that our left-hand side variable corresponds to the year 2005 while the country and industry explanatory variables decribed above refer to the year 2002 whenever possible. The use of lagged independent variables attempts to minimize simultaneity biases. See Appendix C for further details the sources and definitions of these and all other variables used in this paper.

[26] 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.

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.

In total, we have pollution intensity data for 85 manufacturing industries. Table 2 lists 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 2. 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 3 panel A).

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.[27,28] 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 panel B 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.[29]

[27] 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. The year 1987 was the first 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."

[28] 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.

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

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 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.[30]

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.[31] 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.[32]

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

[30] 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. (See EPA, 2005, p.3 and Jacobson, 2002, p.88.)

[31] 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).

[32] 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.

disperses vertically as a result of vertical movements of air, which result from temperature and density vertical profiles.[33] 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.[34] 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".[35] The average concentration of pollution in the urban area is inversely proportional to its ventilation coefficient.[36] 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 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

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

[34] 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.

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

[36] 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.

pollutant concentrations, both in developed and developing countries. (See 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.[37,38]

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[39] (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.[40,41] 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 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.[42] Small scale factors, including altitude, ruggedness and soil type, introduce spatial variation within these broad patterns.

[37] 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.

[38] 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.

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

[40] 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.

[41] 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.

[42] 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.

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. Notice that, for historical reasons, the location of a country's capital tends to predate the rise of manufacturing and is therefore unlikely to reflect concerns on whether its atmospheric conditions lead to more or less pollution dispersion. Thus, to implement our baseline measure of a country's ventilation coefficient, we select the grid-cell where the capital city is located and assign to the latter the average ventilation within the corresponding cell.[43] 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.

As a robustness check, we have also computed the ventilation coefficient of a country as the population-weighted average of the ventilation coefficient across all grid cells corresponding to that country.[44] Figure 3 presents a scatter plot of our baseline, capital-city ventilation coefficient measure against this alternative. The correlation is 0.91 and it is significant at the 1% level. Given the high spatial correlation of our source data across grid-cells, it is not surprising that the cross-country distribution of ventilation coefficients obtained in this fashion is similar our baseline discussed above. We prefer to use the capital-city measure as our baseline because the location of capitals tends to predate the industrial revolution thus it is unlikely to be determined by atmospheric pollution dispersion potential while the current overall geographical distribution of population could be in principle affected by it.

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).[45]

[43] 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.

[44] To do this, we obtain high-resolution, gridded population data from the Population Count Grid dataset assembled by CIESIN/Columbia University, FAO and CIAT (2005). See Appendix C for further details on this source and construction of this alternative measure.

[45] 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 sources refer to Appendix C.

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.[46]

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.[47] From this, we obtain lead content data for 101 countries in 1996.[48] 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. See Table 4 for a ranking of countries according to this measure of environmental regulation stringency.

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

[47] 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.

[48] The year 1996 is the latest for which lead content data is available. Subsequently, leaded gasoline was removed from the market in most countries as a result of global policy campaigns spearheaded by the United Nations Environment Programme. Still, this measure is a good proxy for the relative stringency of regulation across countries to the extent that it reflects a broader environmental policy stance which is persistent over time. Indeed, as we discuss below, this measure is correlated with measures of environmental regulation.

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.[49] 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.[50]

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, where country names are included. Fitted values correspond to the regression reported in column 2, where GDP per capita is included as a control.[51]

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

[50] 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

[51] As a robustness check, in Appendix Table D16 we show that similar estimates are obtained when computing the

4 Empirical strategy and results

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

ventilation coefficient of a country as the population-weighted average of the ventilation coefficient across all grid cells corresponding to that country.

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.[52] 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. 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

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

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.[53] 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 intensity 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.

[53] 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 7 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.

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, 2009a) 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).[54]

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 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

[54] 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).

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.[55] 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 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 (see Bertrand et al., 2004). 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.[56] 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.

[55] 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.

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

4.2 Instrumentation Strategy

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 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 show that the ventilation coefficient is not correlated with observables other than environmental regulation. To see this, first note that 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). Additionally, we check that the instrument is as good as randomly assigned. That is, we show that countries with above median ventilation coefficient do not differ in terms of observables, other than environmental regulation, from countries with below median ventilation coefficient. In particular, in Table 1 we provide cross-country averages of all country-level variables conditioning on whether countries are above or below the median in terms of the ventilation coefficient and environmental regulation. We find that income per capita, capital abundance, skill abundance, oil abundance, and the efficiency of legal institutions are not statistically different in the samples of countries above and below median ventilation coefficient. As expected, all these observables are statistically different in the samples of countries above and below median environmental regulation, suggesting that policy is very likely endogenous. The 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.

To make our instrumentation strategy clear, recall that our estimating equation (17) follows the same logic as a standard differences-in-differences (DD) estimation where we use a continuous measure of the intensity of treatment, namely the stringency of a country's environmental regulation, and a continuous measure of the level of exposure to the treatment, namely an industry's pollution intensity. The identification problem we face in the estimation of equation (17) is that the treatment is not randomly asssigned. Thus, we use the ventilation coefficient, V_c, as an instrument for environmental regulation, E_c. Note that because the treatment (E_c) has heterogenous effects on industries with different levels of pollution intensity (e_i), we are interested in estimating the coefficient on the interaction of environmental regulation in country c and pollution intensity in industry i ($E_c \times e_i$). Thus, we instrument for this interaction ($E_c \times e_i$) in equation (17) using the interaction of the ventilation coefficient in country c and pollution intensity in industry i ($V_c \times e_i$), as described by the following first stage regression equation:

$$E_c \times e_i = \delta_1 \ V_c \times e_i + \delta_2 \ K_c \times k_i + \delta_3 \ H_c \times h_i + \theta_c + \theta_i + \nu_{ic}. \tag{19}$$

The requirements for this instrumentation strategy to be valid are: first, that the ventilation coefficient is a valid instrument for environmental regulation, second, that pollution intensity is exogenous with respect to our outcome of interest.[57] We argued above that the ventilation coefficient satisfies the first requirement. In addition, pollution intensity satisfies the second requirement: it is 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.

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:

$$M_{ic} = \gamma_1 \ V_c \times e_i + \gamma_2 \ K_c \times k_i + \gamma_3 \ H_c \times h_i + \alpha_c + \alpha_i + \varepsilon_{ic}, \tag{20}$$

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%.[58]

[57] See Ozer-Balli and Sorensen (2010) 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).

[58] 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. Finally, Table D17 shows that similar estimates are obtained when computing the ventilation coefficient of a country as the population-weighted average of the

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 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). 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 (19) 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

ventilation coefficient across all grid cells corresponding to that country.

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.[59] 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 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

[59] 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. Finally, Tables D18 and D19 shows that similar estimates are obtained when computing the ventilation coefficient of a country as the population-weighted average of the ventilation coefficient across all grid cells corresponding to that country.

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 suggest a number of directions for future research. The analysis can be extended to the case of green house gases (GHG). In quantitative models of climate change, a crucial ingredient is the degree to which reductions in GHG emissions resulting from policies in advanced countries will result in increases in emissions in developing countries as a result of the relocation of GHG-intensive industries (see, for example, Elliott et al., 2010). Our methodology can be used to estimate this carbon leakage effect. In addition, 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 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.

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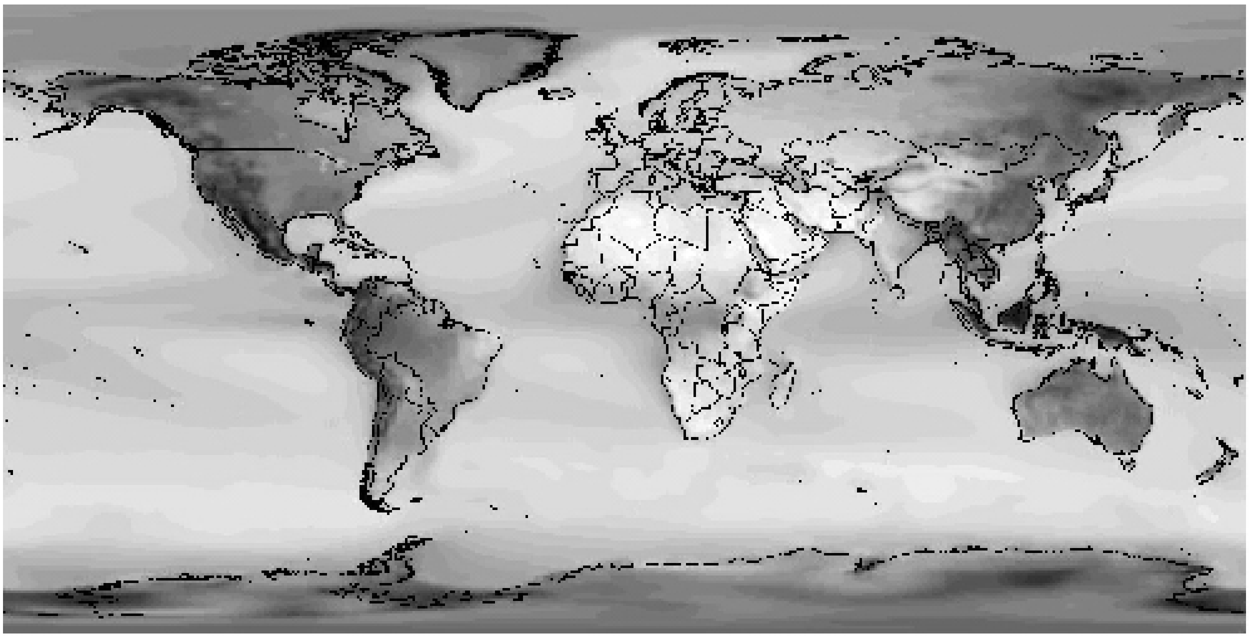
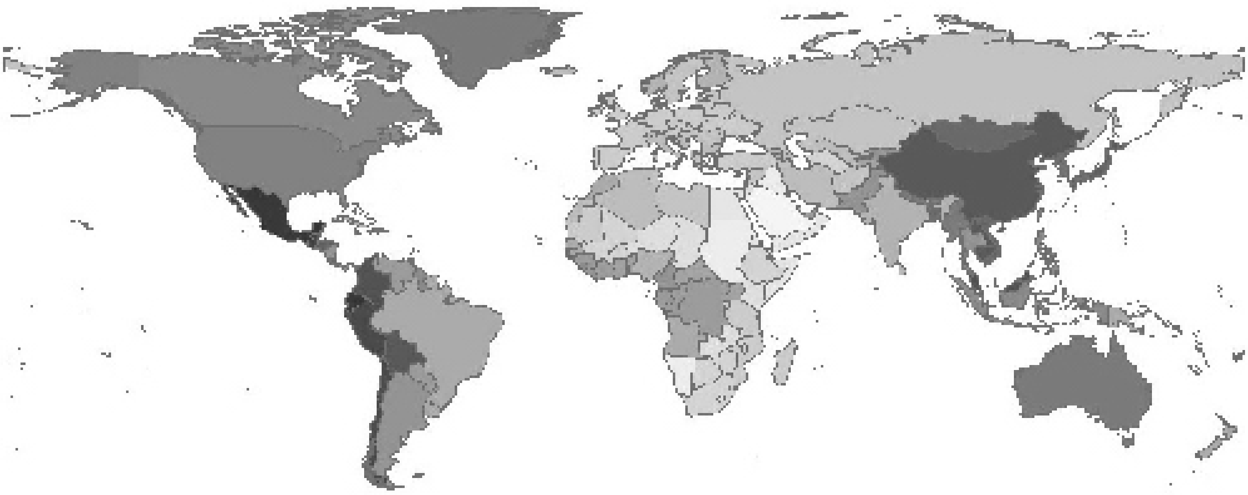
Figure 1
Ventilation coefficient



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 $0.75^{\circ} \times 0.75^{\circ}$ 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 $0.75^{\circ} \times 0.75^{\circ}$ 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.

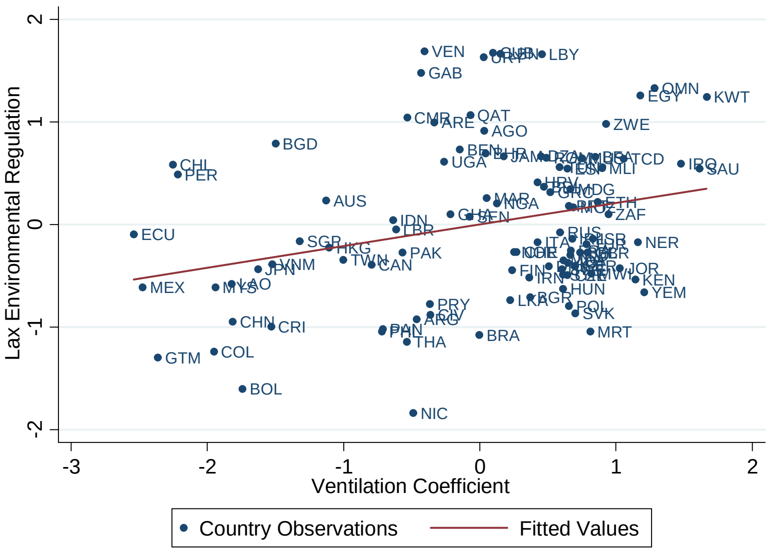
Figure 3

Ventilation coefficient in the capital city and the whole country

Note: The relationship between the ventilation coefficient in the capital city (V_c, used in the main regressions) and the country-wide, population-weighted average. Both variables are in natural logarithms. Country names are included. See the Data Appendix for further details.

Figure 4

Ventilation coefficient and environmental regulation



Note: The figure depicts the partial effect of the ventilation coefficient on environmental regulation corresponding to the regression reported in column 2 of Table 5 where income per capita is included as a control. Both variables are measured in terms of standard deviations from the mean.

Table 1

Lack of correlation between instrument for environmental regulation and observables

	Lax Environmental Regulation			Ventilation Coefficient		
	Above Median	Below Median	Difference of Means	Above Median	Below Median	Difference of Means
Income per capita	8.13	9.37	-1.24***	8.78	8.73	0.05
	(0.16)	(0.12)	(0.20)	(0.18)	(0.15)	(0.23)
Capital Abundance	9.44	11.23	-1.79***	10.41	10.29	0.12
	(0.21)	(0.15)	(0.26)	(0.24)	(0.20)	(0.31)
Skill Abundance	0.59	0.92	-0.33***	0.80	0.72	0.08
	(0.04)	(0.03)	(0.05)	(0.05)	(0.04)	(0.06)
Fertile Land per capita	77.11	82.82	-5.71	67.57	92.17	-24.60
	(12.29)	(15.96)	(20.20)	(9.10)	(17.74)	(20.06)
Oil Abundance	2.55	0.23	2.33**	1.46	1.29	0.17
	(1.17)	(0.12)	(1.16)	(0.96)	(0.70)	(1.18)
Efficiency of Legal Institutions	23.84	34.29	-10.45***	29.70	28.56	1.15
	(1.83)	(1.39)	(2.29)	(1.79)	(1.81)	(2.55)

Note: The table reports the mean of the variables on the left for countries above and below the median lax environmental regulation, and above and below the median ventilation coefficient. For every variable we use the maximum number of observations available: this is 101 for (log) income per capita, (log) capital abundance and fertile land per capita, 99 for oil abundance, 89 for efficiency of legal institutions and 73 for skill abundance. In the sample of 101 countries median lax environmental regulation is 0.38; median ventilation coefficient is 8.22. *** indicates significance of the difference of the means at the 1 percent level, ** at the 5 percent and * at the 10 percent.

Table 2

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 3

Panel A: 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.

Panel B: 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

Country	Value	Country	Value	Country	Value	Country	Value	Country	Value
Argentina	0.00	Poland	0.045	Portugal	0.244	Croatia	0.42	Ethiopia	0.76
Austria	0.00	United Kingdom	0.05	Mauritania	0.25	Pakistan	0.42	Angola	0.77
Bolivia	0.00	Ireland	0.05	Cote d'Ivoire	0.26	Chile	0.43	Liberia	0.77
Brazil	0.00	Hungary	0.05	Greece	0.27	Indonesia	0.45	Uruguay	0.80
Canada	0.00	France	0.06	Jordan	0.30	Yemen	0.45	Bangladesh	0.80
Colombia	0.00	Panama	0.06	Russia	0.30	Morocco	0.50	Egypt	0.80
Costa Rica	0.00	Singapore	0.06	Spain	0.31	Tunisia	0.50	Gabon	0.80
Denmark	0.00	Taiwan	0.06	Turkey	0.33	Kuwait	0.53	Libya	0.80
Finland	0.00	Czech Republic	0.07	South Africa	0.35	Malawi	0.53	Madagascar	0.80
Guatemala	0.00	Malaysia	0.07	Ecuador	0.38	Jamaica	0.54	Mali	0.80
Japan	0.00	Italy	0.08	Bahrain	0.40	Peru	0.56	Benin	0.84
Nicaragua	0.00	Mexico	0.11	Kenya	0.40	Romania	0.56	Burkina Faso	0.84
Slovak Republic	0.00	China	0.13	Laos	0.40	Iraq	0.60	Burundi	0.84
Sweden	0.00	Israel	0.14	Mauritius	0.40	Senegal	0.60	Cameroon	0.84
Thailand	0.00	Philippines	0.14	Moldova	0.40	Oman	0.62	Chad	0.84
Norway	0.00	Bulgaria	0.14	Qatar	0.40	Algeria	0.63	Cuba	0.84
Germany	0.00	Iran	0.19	Saudi Arabia	0.40	Ghana	0.63	Lebanon	0.84
Switzerland	0.02	Australia	0.19	Syria	0.40	Mozambique	0.65	Uganda	0.84
Netherlands	0.02	Paraguay	0.20	United Arab Emirates	0.40	Niger	0.65	Zimbabwe	0.84
Hong Kong	0.03	Sri Lanka	0.20	Vietnam	0.40	Nigeria	0.66	Venezuela	0.85
Belgium	0.04								

Note: Air pollution regulation is maximum lead content (in grams) per liter of gasoline in 1996 multiplied by the market share of leaded gasoline. Higher values indicate laxer air pollution regulation. Data are sourced from World Bank (Lovei, 1998), see the Data Appendix for further details.

Table 5
Ventilation coefficient and environmental regulation
Dependent variable: Lax Environmental Regulation

	1	2	3	4	5	6	7	8	9
Ventilation Coefficient $_c$	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 results

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 (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 results

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 (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 coefficient and comparative advantage in polluting goods - Reduced form results

Dependent variable: Import Share

	1	2	3	4	5	6	7	8	9
Ventilation Coefficient $_c\times$ 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 (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 coefficient and environmental regulation - First stage results

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

	1	2	3	4	5	6	7	8	9
Ventilation Coefficient $_c\times$ 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 (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 square results
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 regressions are 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.