Title

Institutions, Comparative Advantage, and the Environment

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Abstract

This paper proposes that strong financial, judicial, and labor market institutions provide comparative advantage in clean industries, and thereby improve a country's environmental quality. Five complementary tests support this hypothesis. First, industries that depend on institutions are disproportionately clean. Second, strong institutions increase relative exports in clean industries, even conditional on environmental regulation and factor endowments. Third, an industry's complexity helps explain the link between institutions and clean goods. Fourth, a quantitative general equilibrium model indicates that strengthening a country's institutions decreases its pollution through relocating dirty industries abroad, though increases pollution in other countries. Fifth, cross-country differences in the composition of output between clean and dirty industries explain more of the global distribution of emissions than differences in the techniques used for production do. The comparative advantage that strong institutions provide in clean industries gives one under-explored reason why developing countries have relatively high pollution levels.

JEL Classification: F6, F18, F55, F64. H23, O4, O44, P48, Q50, Q56

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1 Introduction

This paper proposes a novel force that affects the global distribution of environmental quality: financial, judicial, and labor market institutions provide comparative advantage in clean industries. This explanation, in addition to existing explanations focused on environmental regulation and factor endowments, provides an important and overlooked contributor to global patterns of pollution. Weak institutions give countries comparative advantage in polluting industries. Strong institutions provide comparative advantage in clean industries. I define polluting industries as those with high emissions of air and water pollution per dollar of revenue, though consider alternative definitions.[1]

I start by documenting that countries with stronger national institutions have better ambient air and water quality. While this is consistent with the paper's hypothesis, it is a weak test since polluted and unpolluted countries differ along dimensions besides institutions, and since institutions may affect pollution through channels besides comparative advantage.

I then use five complementary approaches to assess how institutions contribute to environmental quality through comparative advantage. First, I find that across industries, dependence on strong institutions is positively correlated with an industry's "clean index," i.e., how little pollution it emits per dollar of revenue. This reflects the extent to which each industry depends on each institution. For example, clean industries predominantly use inputs that are traded in bilateral contracts rather than in open exchanges or referenced-priced in industry catalogs, and thus clean industries disproportionately need strong judicial systems to enforce bilateral contracts. Similarly, clean industries disproportionately fund capital investment using external credit institutions like banks. These comparisons also clarify why institutions provide comparative advantage in clean industries—the production technology, capital structure, and volatility of clean industries disproportionately benefit from institutions.

Second, stronger national institutions increase exports in clean industries. This provides direct evidence of comparative advantage. Institutions have large estimated impacts on pollution, with comparable importance for clean industries as environmental regulation or factor endowments. Trade research assesses how the interaction of a country's endowments with an industry's reliance on that endowment (e.g, the interaction of a country's capital stock with an industry's capital intensity) predicts industry-specific trade flows. I extend this approach to study how institutions affect the comparative advantage of clean industries. I report estimates from a cross-section of trade; panel estimates comparing changes in national institutions against changes in international trade over 20 years; looking across manufacturing and all industries; comparing across 15 different measures of institutions and 8 different measures of environmental regulation; instrumenting institutions with countries' legal origins, rates of settler mor-

[1] "Clean industries" in some settings denotes solar, wind, or other forms of energy generation that emit or no pollution. I use a broader interpretation of this phrase to describe any industry with relatively low pollution emissions per dollar of revenue.

tality, or population density in the year 1500; using US or multi-country data on pollution intensity; and using intra-national data across states of India.

Third, I investigate why clean industries depend disproportionately on institutions. I find that clean industries depend on sophisticated, skilled, and specialized inputs, i.e., complex inputs. These explanations help account for the comparative advantage institutions provide in clean industries.

Fourth, I use a quantitative general equilibrium model to assess how improving institutions in some countries changes pollution in all countries. I use a structural gravity model with pollution (Costinot and Rodriguez-Clare 2014; Shapiro 2021) where national institutions change a country's productivity across industries. The comparative advantage regressions of the earlier sections estimate parameters describing the productivity benefit of institutions. I find that improving institutions in countries where they are initially weak decreases pollution in those countries but increases it in others, due to changing the output share of dirty industries. For example, a counterfactual which improves institutions in Latin America to match institutional quality in North America would decrease pollution in Latin America by up to 20 percent but increase pollution in other regions, by reshuffling the location of dirty industries.

The first four sections find that comparative advantage, driven by institutions, affects the global distribution of pollution by changing the composition of output across industries. This finding initially seems to challenge existing literature, discussed later, which finds that techniques used for producing goods rather than the composition of output across industries accounts for aggregate patterns of environmental quality. Existing research looks at changes in pollution across time and within a country, so does not analyze cross-country differences in environmental quality. To understand how the findings of this paper's first four parts relate to this existing evidence, the fifth approach of this paper adapts a decomposition used in existing literature, but modifies it to study environmental quality across countries.

Specifically, the fifth approach decomposes the extent to which cross-sectional differences in pollution across countries reflect differences in the scale of total output, the composition of output across industries, and the techniques used to produce output in a given industry. For example, it asks: how would India's pollution change if India used US production techniques versus if India's composition of output across industries matched the US distribution? The decomposition includes all activities in the economy, including but not restricted to manufacturing, agriculture, utilities, and household production.

I find that composition has importance similar to or greater than technique in explaining international differences in environmental quality. This suggests that comparative advantage and its determinants could meaningfully affect global patterns of environmental quality. This decomposition helps reconcile the important role of institutions and comparative advantage from this paper's first several sections with the limited scope for comparative advantage to affect pollution that some readers take from the existing decomposition literature.

The paper's five approaches complement each other. The positive correlation between an industry's dependence on institutions and its clean index provides a reason for why the trade regressions and the quantitative model find that institutions provide comparative advantage in clean industries. That positive correlation also motivates the analysis of mechanisms—why do clean industries need institutions? The trade regressions estimate parameters that the quantitative model uses. The decomposition of scale, composition, and technique reconciles results from the earlier regressions with prior literature. Finally, all five approaches speak to the same research question: how and why do institutions affect pollution through comparative advantage?

One explanation of this paper's conclusions is that they combine a few ideas that are each fairly simple. First, comparative advantage drives international trade. Recent tests of Ricardian models, Heckscher-Ohlin models, and others find empirical support for this classic idea (Chor 2010; Costinot and Donaldson 2012; Morrow 2022). Second, institutions provide a source of comparative advantage (Nunn 2007; Levchenko 2007; Costinot 2009; Chor 2010; Manova 2013; Boehm 2022). Third, industries that need strong institutions are clean. I provide the first test and evidence of the third channel. It describes correlation but need not reflect causation—the key question is whether the industries that benefit from institutions are relatively clean, not whether depending on institutions or some other correlated variable causes an industry to be clean.

This paper departs from existing work in several ways. I believe it is the first comprehensive analysis of how institutions contribute to international differences in environmental quality through comparative advantage. This provides a new mechanism underlying the relationship between international trade and the environment, since institutions receive little attention in the trade-environment literature. Existing research on trade and the environment focuses on environmental regulation and endowments of capital and labor as the main drivers of international differences in environmental quality (Antweiler, Copeland and Taylor 2001).[2] The idea that regions may use weak levels or enforcement of environmental policy to attract dirty industries (the "Pollution Havens Hypothesis") is among the most influential ideas in research on trade and the environment, and I build on literature seeking to understand the limited empirical support for this Hypothesis (Cherniwchan, Copeland and Taylor 2017).[3] The Environmental Kuznets Curve literature (Grossman and Krueger 1995) proposes that a country's pollution has an inverted U-shaped relationship to income per capita. Interpretations of that pattern attribute it to consumer preferences, structural transformation from agriculture to manufacturing to services, increasing

[2] A few papers refer to environmental regulation, and Jones and Manuelli (2001) theoretically analyze voting rules, as types of institutions. I use "institutions" to refer to judicial, financial, and labor market institutions, which I distinguish from environmental regulation, though I carefully compare them.

[3] Given the importance of the Pollution Havens Hypothesis, a brief history is informative and I do not think is available elsewhere. The first published mention of "pollution havens" appears to be from the late 1960s, in discussions of how US states used weak environmental policy to attract industrial activity (Hughes 1967; Lieber 1968; Metzler 1968). Russell and Landsberg's (1971) paper in *Science* popularized use of the phrase to describe international industry relocation. The pollution havens "hypothesis" was introduced in the early 1990s around environmental debates involving the North American Free Trade Agreement (Molina 1993; Birdsall and Wheeler 1993; Harrison 1994).

returns to pollution abatement, or voting rules that determine environmental regulation, among others (Arrow et al. 1995; Stokey 1998; Andreoni and Levinson 2001; Jones and Manuelli 2001). The evidence for the inverted-U pattern is mixed (Stern 2017), and international comparisons of pollution find higher levels in developing countries for at least some pollutants (Greenstone and Hanna 2014; Jayachandran 2022). Andersen (2016; 2017) finds that ambient air pollution declines when a country creates a credit bureau and that US manufacturing firms with better credit ratings have lower pollution emissions.

Unlike much research at the intersection of development and environment, which focuses on demand-side reasons like income for why poor countries have more pollution (Greenstone and Jack 2015), I focus on how comparative advantage instead represents a supply-side story wherein providing environmental quality is more costly in countries with weak institutions. Classic work emphasizes that property rights over natural resources like timber or groundwater increase investment in those resources, since owners benefit from the resources' long-run value, though does not attribute environmental benefits of institutions to comparative advantage (Coase 1960; Chichilnisky 1994).

Parts of this paper distinguish how environmental regulation versus institutions drive location choices of dirty industries. Environmental regulation takes many forms, which can be challenging to quantify as a single national measure. I build on existing work, which typically focuses on one measure of regulation, by compiling eight data series with country-level measures of environmental regulation, which I analyze individually and also aggregate. The eight data series measure the executives' perceptions of environmental regulation enforcement and stringency; participation in international environmental treaties; standards for sulfur in diesel and lead in gasoline; environmental taxes as a share of GDP; and the level of ambient air quality standards for particulate matter and sulfur dioxide. The main results incorporate the first four, which are available for most countries in the analysis; and sensitivity analyses incorporate all eight, which cover a subset of countries. While no one of these alone provides a perfect measure of regulation, together they provide a more complete picture than has been previously available.

This paper also shows that approaches in the trade literature used to study comparative advantage can shed light on environmental quality. Research has studied how capital, skills, and institutions drive international specialization (Rajan and Zingales 1998; Romalis 2004; Nunn 2007; Chor 2010; Cuñat and Melitz 2012). Broner, Bustos and Carvalho (2011) find that environmental regulation discourages dirty production, though do not examine how institutions affect dirty industries. Firms can respond to weak contracting environments through vertical integration (Grossman and Hart 1986; Hart and Moore 1990; Antras 2003); one could interpret this paper's estimates as net of any such firm adaptive responses.

Finally, I provide what I believe is the first decomposition of how scale, composition, and technique explain cross-country differences in environmental quality. The results of this decomposition differ from the prevailing view that composition is an unimportant channel for understanding broad global environmental patterns. Following Grossman and Krueger (1993) and then Copeland and Taylor (1994), research has asked whether changes in the scale of production, the composition of production across industries, or the techniques used to produce goods within industries most accounts for differences in environmental quality. Recent analyses of the US, EU, Canada and many other countries typically find that technique, rather than composition, explains most differences in environmental quality within a country and over time (Grether, Mathys and de Melo 2009; Levinson 2009; Brunel 2016; Shapiro and Walker 2018; Copeland, Shapiro and Taylor 2022). Because standard Heckscher-Ohlin models predict that comparative advantage would primarily cause differences in environmental quality through composition, some work proposes based on this empirical finding that canonical theories of comparative advantage do not primarily account for international differences in environmental quality. While those findings account for environmental change within a country and over time, this paper instead provides such a comparison across countries within a year, and finds a more important role for composition effects. It is unclear why existing work has applied this decomposition to the time series within a country rather than the cross-section across countries; the recent availability and limited environmental applications of global multi-region input-output tables in environmental economics may contribute.

Before proceeding, I clarify the paper's scope. I analyze how institutions affect environmental quality through comparative advantage. This question has reasonable internal validity in regressions interacting country and industry characteristics and provides quantitatively important effects. It also parallels many trade papers examining how institutions drive comparative advantage overall (Nunn 2007; Levchenko 2007; Costinot 2009; Chor 2010; Manova 2013; Boehm 2022). I largely leave analysis of other channels besides comparative advantage for institutions to affect environmental quality to future work.

I also clarify a broad question on the relative potential importance of environmental regulation. How could institutions, which do not intentionally target clean or dirty industries, have comparable importance for industry location choice as environmental policy, which targets dirty firms and industries? Cost structure provides a natural explanation. Research suggests that for the dirtiest industries, environmental regulation increases costs by up to a few percent (Becker and Shadbegian 2005; Greenstone, List and Syverson 2012; Shapiro and Walker 2018). By contrast, through changing the productivity of using intermediate goods or factors, institutions have potential to change a large majority of a firm's cost structure.

I proceed as follows. Section 2 describes data. Section 3 provides cross-industry correlations of dependence on institutions and an industry's clean index. Section 4 estimates trade regressions interacting national institutions with an industry's clean index. Section 5 investigates which industry characteristics account for the relationship of institutions and pollution. Section 6 uses a quantitative model of institutions and the environment. Section 7 decomposes scale, composition, and technique. Section 7 concludes.

2 Data

Appendix Table 1 summarizes variables and Appendix A provides additional details. I scale all environmental variables so more positive values represent better environmental quality.

2.1 Country Variables

I use country-level measures of each institution for the year 2012 or closest available year.[4] I measure each institutions in z-scores, with a higher value denoting better institutions. Appendix A.1 describes measures of institutions and environmental regulation for sensitivity analyses.

I use standard data to measure each institution (Rajan and Zingales 1998; Romalis 2004; Nunn 2007; Chor 2010; Cuñat and Melitz 2012; Manova 2013). I measure financial institutions as the ratio of private credit by deposit and money institutions to GDP, as reported in the World Bank's Financial Structure Database. I measure judicial institutions from the World Bank's Rule of Law index, which reflects the "quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence" (Kaufmann, Kraay and Mastruzzi 2011, p. 223). I measure labor market institutions from the Heritage Foundation (2021)'s labor market freedom index, which reflects hindrance to hiring workers; rigidity of hours; and other inflexibility.

I measure labor institutions as labor market flexibility. This contrasts with another possible concept, the presence of a strong social safety net. I can quantify the extent to which each industry benefits from flexibility, according to the volatility of firm sales (Cuñat and Melitz 2012). It is harder to measure the dependence of each industry on the safety nets measure of labor market institutions.

I use eight different measures of national environmental regulation. I primarily analyze the first principal component of the four measures of regulation with the fewest missing values. I report sensitivity analyses that aggregate all eight measures via z-scores or via percentiles, which unlike principal components deal with missing values. I also analyze each of the eight measures of regulation separately. The eight measures are as follows: surveys of executives about environmental policy enforcement and about environmental policy stringency; the number of environmental treaties each country has signed; the ratio of environmental tax revenue to GDP; the 24-hour numerical air quality standards for particulate matter and sulfur dioxide;[5] lead standards for gasoline; and sulfur standards for diesel. The principal components measure combines the diesel sulfur standard, environmental regulation stringency, environmental regulation enforcement, and environmental treaties.

I measure factor endowments from standard data. I measure capital endowments as the log of the value of a country's capital stock per worker, and skill endowments as the Penn World Tables calculation

[4] I use 2012 since several data come from the US Economic Census, collected in years ending in 2 and 7.

[5] These are the two standards with the fewest missing values across countries.

of a country's human capital index (Feenstra, Inklaar and Timmer 2021).

I analyze air ambient pollution data on the national urban mean of particulate matter smaller than 2.5 micrometers ($PM_{2.5}$), averaged over 2014-2022. I also analyze measures of biochemical oxygen demand, which provides a common omnibus measure of water pollution (Keiser and Shapiro 2019).

Appendix Table 2, Panel A, shows correlations between country variables. Financial and judicial institutions have a positive correlation. Labor market institutions have weaker correlation with other institutions. Environmental regulation are positively correlated with institutions, capital, and skills.

2.2 Industry Variables

I measure most industry variables for about 350 US 6-digit North American Industry Classification System (NAICS) manufacturing industries in 2012. I report sensitivity analyses using data from Exiobase, which allow industry characteristics including pollution to differ by country. Appendix A.2 discusses possible concerns about measures of industries' dependence on institutions.

The main results use US industry data, for several reasons. The US has greater industry detail and better emissions data than most countries. Emissions data in Exiobase rely on imputed pollution information, albeit flexibly and comparably, for many countries based on technology data (Stadler et al. 2018). The variables used to clarify why clean industries depend on institutions are available for the US only. The US Census of Manufactures also measures cumulative capital stock, which is harder to measure well for every country×industry globally.[6] Using US data also ensures that industry rates are exogenous to conditions in other countries. Reporting results with Exiobase also addresses potential bias from assuming that US pollution rates represent all countries (Ciccone and Papaioannou 2023).

I use common measures of each industry's factor and institution intensity (Rajan and Zingales 1998; Romalis 2004; Nunn 2007; Chor 2010; Cuñat and Melitz 2012). Measures of each industry's dependence on capital and skills are straightforward. I measure an industry's dependence on financial institutions as the share of the industry's capital expenditures that internal cash flow do not support, using Compustat North America data. I measure an industry's dependence on judicial institutions as the share of the industry's inputs, measured from input-output tables, that are not traded on open markets or reference priced (Rauch 1999). This is also positively correlated with the prevalence of contract litigation (Boehm 2022). I measure an industry's dependence on labor market institutions as the standard deviation of within-firm sales growth, using Compustat data, weighted across firms by each firm's employment.

I measure each industry's clean index from data on air and water pollution emissions. I analyze air and water pollution because they can have large local welfare effects, are the focus of the trade-

[6] Focusing on manufacturing also limits concern that discovery and exports of natural resources from the mining sector could directly influence institutions through the "resource curse." A sensitivity analysis includes all industries and not just manufacturing.

environment literature, and are feasible to attribute to individual industries.

I measure the short tons of air pollution emitted from the 2011 National Emissions Inventory, a comprehensive plant-level emissions dataset collected by the US Environmental Protection Agency. I consider the five "criteria" pollutants that are most widely measured and the focus of regulation: carbon monoxide, nitrogen oxides, particulate matter smaller than 2.5 micrometers ($PM_{2.5}$), sulfur dioxide, and volatile organic compounds. For each pollutant, I calculate log emissions per dollar of revenue. I measure revenues from the 2012 Census of Manufactures. I measure an industry's air pollution rate as the first principal component of the five log pollutant-specific rates. Appendix A.1 discusses reporting thresholds in the air pollution data. For water pollution, I measure the log of the total pounds of emissions from the Discharge Monitoring Reports of the US Environmental Protection Agency (EPA) per dollar of revenue (USEPA 2020). I measure an industry's clean index as minus one times the first principal component of the air and water pollution emission rates. I report sensitivity analyses using country×industry data from Exiobase, which measures air but not water pollution, and using the Leontief Inverse matrix to account for emissions embodied in value chains of each industry, including electricity.

Appendix Table 2, Panel B, shows pairwise correlations between industry characteristics. Dependence on judicial and financial institutions have a positive correlation. Dependence on judicial and labor market institutions are independent. Clean industries have stronger dependence on institutions.

2.3 Other Variables

I measure bilateral trade from the BACI database, created by CEPII. I aggregate data to 134 individual countries with non-missing values of key variables, plus one rest-of-world region. I concord these data to distinguish over 350 six-digit NAICS industries. I use applied tariff rate data from CEPII's Market Access Map (Macmap) database, which accounts for regional and free trade agreements, tariff rate quotas, and other detailed tariff characteristics. Applied tariffs represent the statutory tariff rate, which is weakly less than preferential (Most Favored Nation) tariffs. A 2-digit Harmonized System (HS) code version is online; I purchased the 6 digit HS code version (Guimbard et al. 2012).

I use data from Exiobase, version 3.8.1, industry-by-industry data (Stadler et al. 2018), to separate scale, composition, and technique. Exiobiase is a multi-region input-output table, like the World Input Output Database or Eora. I use Exiobase since it has 163 industries, much more than other world input-output tables. I also estimate the quantitative model using trade, production, and air pollution data from Exiobase aggregated to 10 regions and 21 industries. I use this aggregation, following Costinot and Rodriguez-Clare (2014) and Shapiro (2021) since it easily summarizes broad geographic patterns.[7] The quantitative model uses sector-specific trade elasticities aggregated across four studies (Caliendo

[7]With far more detailed regions or industries, the algorithm for analyzing counterfactuals does not always converge.

and Parro 2015; Shapiro 2016; Giri, Yi and Yilmazkuday 2020; Bagwell, Staiger and Yurukoglu 2021; see also bartelme:etal:2021 and Shapiro 2021).

I report one analysis of state production in India, using microdata from India's 2015-2016 Annual Survey of Industry. The dependent variable in regressions measures gross sales. I measure institutions according to existing measures (Dougherty 2009; Boehm and Oberfield 2020).

2.4 Cross-Country Comparisons

Figure 1 shows a cross-sectional correlation of national institutions and environmental quality:

$$Z_i = \rho_0^C + \rho_1^C I_i + \epsilon_i \tag{1}$$

Here Z_i measures ambient air or water quality in country i and I represents national institutional quality. Equation (1) provides a starting point for research on institutions and environmental quality, and I do not believe it has been previously reported. It does not reveal causal evidence, since institutions may be correlated with other variables influencing pollution. It also provides no evidence on whether institutions might affect pollution through comparative advantage or other channels.

Figure 1 shows binned scatter plots of equation (1). Each observation underlying a graph represents a country. The blue dots represent mean values within equal-sized bins. The red line shows the linear trend. The y-axis in the graphs on the left describes ambient air or water quality. The x-axis measures institutional quality in z-scores. The top two graphs describe financial institutions, the middle two describe judicial institutions, and the bottom two describe labor market institutions.

Figure 1 shows that across countries, stronger institutions have a positive correlation with better air and water quality. Some relationships are roughly linear. Others are less robust. Panel E, but not other graphs, has a slight U shape reminiscent of the Environmental Kuznets Curve literature (Grossman and Krueger 1995). Figure 1 uses the highest-quality data on the pollutant with the greatest health damages, particulate matter. Appendix Figure 1 finds similar patterns on two other relevant pollutants that have been a focus of trade-environment research since Grossman and Krueger (1995) and Antweiler, Copeland and Taylor (2001)—nitrogen dioxide and sulfur dioxide.

Subsequent sections use regression and model-based tests of whether and how stronger national institutions cause an improvement in environmental quality through comparative advantage.

3 Cross Industry Comparisons

I first ask whether the industries that depend on institutions are clean. Existing research finds that national institutions provide comparative advantage in the industries which depend on institutions. If an industry's clean index and its dependence on institutions covary positively, then the existing research could also imply that national institutions provide comparative advantage in clean industries.

I measure the cross-sectional relationship of each industry's dependence on institutions with the industry's clean index—how little air and water pollution industry s emits per dollar of sales:

$$Z_s = \rho_0^I + \rho_1^I I_s + \epsilon_s \tag{2}$$

I measure Z_s, the clean index of industry s, as minus one times the first principal component of log air and water pollution per dollar. The term I_s represents the extent to which industry s depends on institutions, discussed in Section 2.2. If $\rho_1^I > 0$, then clean industries depend more on institutions. This would give institutions potential to provide comparative advantage in clean industries.

Table 1 describes the five cleanest and dirtiest manufacturing industries. While Table 1 only provides anecdotal comparisons, it previews the general finding that cleaner industries depend more on stronger institutions. Table 1 uses only US data and thus holds national institutions and environmental regulation fixed. Panel A shows that clean industries depend on strong institutions. For example, column (1) shows that the fluid power pumps and motors industry is 2.4 standard deviations cleaner than the mean industry. Columns (2) through (4) show that this industry depends 1.5 standard deviations more than the mean manufacturing industry does on financial institutions, 0.7 standard deviations more on strong judicial institutions, and 0.9 standard deviations more on flexible labor market institutions.

Panel B of Table 1 shows that dirtier industries depend less on institutions. Gypsum product manufacturing, one of the dirtiest manufacturing industries, depends on financial institutions 0.6 standard deviations less than the mean manufacturing industry does. The gypsum products industry also depends on judicial institutions 1.2 standard deviations less than the mean manufacturing industry does, and also depends on labor market institutions 1.2 standard deviations less than the mean industry does.

Column (5) of Table 1 shows mostly positive values for clean industries in Panel A, indicating that they depend more than average on institutions; but negative values for dirty industries in Panel B, indicating that they depend less than average on institutions. On average, the cleanest industries in Table 1 depend 1.9 standard deviations more on institutions than the dirtiest industries do.

Figure 2 shows binned scatter plots describing the relationship between an industry's clean index and its dependence on institutions. Each observation underlying a graph represents one industry. Each blue circle shows the mean for one of 15 evenly-sized bins and the red line shows the linear trend.

The upward-sloping lines in Figure 2 imply that cleaner industries depend more on stronger institutions. Panel A shows that industries that depend relatively more on financial institutions, and thus rely more on external finance and less on free cash flow for their capital investments, are cleaner. Panel B shows that industries which use inputs that are differentiated, and thus depend more on strong judicial institutions, are cleaner. Panel C shows that industries which have volatile sales, and thus may more often seek to hire and fire workers so benefit from flexible labor market institutions, are cleaner. The coefficients in the graphs, corresponding to equation (2), show that the magnitudes of these associations range from 0.14 for labor market institutions to 0.49 for judicial institutions.

This section finds that the industries which depend on institutions are clean. One can combine this with the finding from existing research, that strong national institutions provide comparative advantage in industries that depend on institutions, to indirectly conclude that institutions provide comparative advantage in clean industries. Rather than relying on that indirect logic, the next section interacts country and industry characteristics to provide direct tests of comparative advantage in clean industries.

4 Regressions: Direct Tests of Comparative Advantage

4.1 Comparative Advantage in All Industries

As Section 6 will discuss, multi-sector Ricardian trade models lead to the following gravity equation for international trade (Costinot, Donaldson and Komunjer 2012; Costinot and Rodriguez-Clare 2014):

$$X_{ij,s} = \xi \frac{T_{i,s}(c_{i,s}\phi_{ij,s})^{-\theta_s}}{(P_{j,s})^{-\theta_s}} X_{j,s} \tag{3}$$

Here $X_{ij,s}$ is the value of bilateral trade from origin country i to destination j in industry s, $T_{i,s}$ is the origin×sector technology, $c_{i,s}$ is the unit production cost, and country×sector expenditure is $X_{j,s} \equiv \sum_i X_{ij,s}$. The full trade cost is $\phi_{ij,s} \equiv \tau_{ij,s}(1 + t_{ijs})$. Goods face iceberg trade costs $\tau_{ij,s} \geq 1$, where τ goods must be shipped for one to arrive, and tariffs $t_{ij,s}$. Here θ_s describes the (trade) elasticity of bilateral trade with respect to trade costs. The importer×industry price index is $P_{j,s}$. The importer spends $X_{ij,s}$ on (ij, s) goods. The term ξ represents a constant function of model parameters.

I link equation (3) to country endowment×industry regressions through the following assumptions:

$$lnX_{j,s} - \theta_s lnP_{j,s} = \zeta_{j,s} \tag{4}$$

$$lnT_{i,s} = \alpha E_i I_s + \sum_f \beta_f E_i^f I_s^f + \pi R_i Z_s + \omega_{i,s} \tag{5}$$

$$ln\xi - \theta_s lnc_{i,s} - \theta_s ln\phi_{ij,s} = \gamma t_{ij,s} + \eta_{ij} + \omega_{ij,s} \tag{6}$$

$$\epsilon_{ij,s} = \omega_{i,s} + \omega_{ij,s} \tag{7}$$

Equation (4) states that the importer×industry fixed effects $\zeta_{j,s}$ equal the difference of importer×industry log expenditure and scaled prices. Equation (5) states that a country×sector's productivity reflects the interactions of endowments and industry characteristics, plus a stochastic term $\omega_{i,s}$. Equation (6) states that tariffs, bilateral fixed effects η_{ij}, and the error $\omega_{ij,s}$ capture the effects of unit production costs and trade frictions. In these equations, E_i represents the quality of institutions in exporter i, E_i^f is a country's endowment of factor f, I_s^f is the dependence of industry s on factor f, R_i is the stringency of environmental regulation, and Z_s is the clean industry index.[8] The left side of equations (4) through (7) describe components of equation (3). The right side of these equations describe terms that data report or regressions can estimate. I do not include ad valorem measures of non-tariff barriers since they are generally available at the importer×industry level but do not differ by exporter, and thus are perfectly collinear with the fixed effects $\zeta_{j,s}$ (Kee, Nicita and Olarreaga 2009; Shapiro 2021).

Under assumptions (4) through (7), the natural log of equation (3) becomes the following:

$$lnX_{ij,s} = \alpha E_i I_s + \sum_f \beta_f E_i^f I_s^f + \pi R_i Z_s + \gamma t_{ij,s} + \zeta_{j,s} + \eta_{ij} + \epsilon_{ij,s} \tag{8}$$

Many papers test for comparative advantage by interacting exporter endowments with industry characteristics. Equations (4) through (7) describe one way to derive such an equation from a Ricardian trade model. The term α reflects comparative advantage due to institutions, β_f reflects comparative advantage due to factor endowments, and π reflects comparative advantage due to environmental regulation.

I add a few practical notes. I report estimates either with an index of institutions or separating financial, judicial, and labor market institutions. Factors include a country's capital-labor ratio and skills. Regressions cluster standard errors by country pair. I show standardized beta coefficients to facilitate comparison of magnitudes across variables. I also report Poisson pseudo-maximum likelihood (PPML) versions of equation (8), partly to address possible bias from excluding the log of zero trade flows (Silva and Tenreyro 2006). Even if some country endowments affect others, e.g., if institutions affect factor endowments or environmental regulation, equation (8) reflects effects of one country endowment conditional on others. For example, one could think of comparing countries with similar quality institutions but different stringency of environmental regulation.

Equation (8) and extensions address three econometric issues. Institutions may be measured with error. Institutions may be correlated with other country characteristics. Trade and production may also affect institutions. I use many approaches to addressing these potential concerns—I compare different measures of institutions, construct an index of institutions, use multiple predetermined instruments for institutions, focus on interactions of a country's institutions with an industry's characteristics, and exploit variation in institutions across time within a country and across states within a country.

[8]Equation (5) includes factors E_i^f. Alternatively, one could describe a model with multiple factors. Equations (4)-(7) use a single factor since they provide simple conditions for a gravity model to generate the endowment×industry intensity variables in the literature.

Results

Table 2, Panel A, examines comparative advantage in a standard setting, corresponding to equation (8). The first four columns study comparative advantage due to institutions. For example, column (1) analyzes the interaction of a country's financial institutions with an industry's dependence on financial institutions. Column (5) considers the interaction of a country's environmental regulation and an industry's clean index. Columns (6) and (7) estimate comparative advantage due to factors of production. Column (8) studies tariffs. Columns (9) and (10) consider all these explanations at once.

Table 2, Panel A, shows that most institutions and factors provide comparative advantage. This echoes existing work, though incorporates environmental regulation. Column (1) shows that countries with strong financial institutions export relatively more in industries that depend on financial institutions. The coefficient indicates that for an industry that depends one standard deviation more than average on financial institutions, improving a country's endowment of financial institutions by one standard deviation increases log exports by 0.019 standard deviations. This indicates that financial institutions provide a source of comparative advantage. Columns (2) through (4) show that similar patterns hold for other institutions. Column (5) shows that environmental regulation provides a source of comparative advantage in clean industries, which supports the Pollution Haven Hypothesis. Capital has less importance on its own, though is more important in the pooled regressions of columns (9) and (10). Column (7) shows a similar pattern for skills. Column (8) finds that tariffs discourage trade.

Because Table 2 shows standardized beta coefficients, we can compare their magnitudes. Consistent with Heckscher-Ohlin models, the largest source of comparative advantage in the pooled regression of columns (9)-(10), Panel A, is a country's skill endowment. Capital matters less. In all these estimates, institutions have larger predictive power for trade than environmental regulation does. The role of environmental regulation here nonetheless suggests that the Pollution Havens Hypothesis is important to understanding trade and comparative advantage broadly.

One explanation for the small estimated effect of the capital/labor ratio in Table 2, column (6), is the lack of control for environmental regulation, since polluting industries have high capital/labor ratios. Adding the environmental regulation endowment×intensity variable to this regression increases the coefficient on the capital/labor ratio to be larger and statistically significant. The estimate for the capital/labor ratio in columns (9)-(10) also fits this explanation. Table 2 thus demonstrates the relevance of environmental policy in explaining comparative advantage overall.

4.2 Comparative Advantage in Clean Industries

Findings in Section 4.1 and previous work that institutions provide comparative advantage, and in Section 3 that the industries that benefit from institutions are clean, together imply that institutions provide comparative advantage in clean industries. I now report the following direct test of this hypothesis:

$$lnX_{ij,s} = \alpha^C E_i Z_s + \sum_f \beta_f^C E_i^f I_s^f + \pi^C R_i Z_s + \gamma^C t_{ij,s} + \zeta_{j,s}^C + \eta_{ij}^C + \epsilon_{ij,s}^C \quad (9)$$

Equation (9) tests whether countries with strong institutions export more in clean industries. It resembles the canonical gravity equation (8), but interacts institutions with an industry's clean index, rather than an industry's dependence on institutions. The coefficient α^C represents the mean increase in log exports for an exporter with institutional quality E_i in an industry with clean index Z_s. The country-pair fixed effects η_{ij}^C adjust for effects of the exporter's institutional quality. The destination×sector fixed effects $\zeta_{j,s}^C$ adjust for the industry's clean index Z_s. The coefficient α^C reflects only the interaction of a country's institutional quality and an industry's clean index.

Results

Figure 3 graphs raw data. Each graph describes three variables: the horizontal axis describes an industry's clean index; the vertical axis plots a country's exports in each industry, normalized to mean zero; and the two lines describe countries with strong versus weak institutions. Figure 3 shows that countries with strong institutions specialize in cleaner industries. Panel A describes two example countries: Tajikistan, with weak institutions; and Switzerland, with strong institutions. I plot a nonparametric local linear regression across industries within each country or group of countries. The upward-sloping dashed line in Panel A indicates that Switzerland exports more in clean than dirty industries. The relationship of Swiss exports to an industry's clean index is monotone and approximately linear. The downward-sloping solid line in Panel A indicates that Tajikistan exports relatively less in clean industries. The difference in exports between clean and dirty industries here is economically large.

Figure 3, Panel B, finds similar patterns for all countries. I separate countries into two groups: the dashed red line describes countries with stronger national institutions than the median country; the solid blue line describes countries with weaker institutions than the median country. The X-shaped figure in the global graph in Panel B echoes the shape of the two-country graph in Panel A—countries with strong institutions specialize in clean industries, and countries with weak institutions specialize in dirty industries. In Panel B, the relationship between log exports and an industry's clean index is approximately linear within each country group. Appendix Figure 2 shows two theoretically-derived measures of revealed comparative advantage; in both cases countries with weak institutions specialize in dirty industries, though the specialization of countries with strong institutions in clean industries is clearer in in the measure of Costinot, Donaldson and Komunjer (2012) than that of Balassa (1965).

Table 2, Panel B, estimates equation (9). Columns (1) through (3) consider each type of institution separately. Column (4) analyzes the index of institutions. Columns (9) and (10) pool these estimates.

Table 2, Panel B, finds that countries with strong institutions specialize in clean industries. Most estimates for institutions are positive and statistically significant. Estimates separating institutions in columns (1) through (3) and pooling them in column (9) suggest that financial institutions provide a larger source of comparative advantage in clean industries than judicial or labor market institutions do.

It is unclear what existing evidence would predict regarding this greater role for financial institutions in clean production. Figure 2 finds that judicial institutions have the strongest correlation with a measure of dependence on institutions, Appendix Table 2 also finds that judicial institutions have the strongest correlation with an industry's clean index. At the same time, several of these institutions have strong positive correlation, which can make them complex to separate empirically when jointly included in the same regression (Chor 2010). Financial institutions, unlike others, do have existing research highlighting their direct importance for clean production (Andersen 2016, 2017).

In Table 2, Panel B, Column (10) shows that for an industry one standard deviation cleaner than the mean, a country with one standard deviation stronger institutions has about 4 percent of a standard deviation higher log exports. Column (6) supports the Pollution Havens Hypothesis by finding that environmental regulation drives specialization in clean industries. It also finds that institutions are at least as important as environmental regulation to explaining countries' specialization in clean versus industries. The literature on trade and the environment focuses on how environmental regulation affects location choices of clean industries and generally abstracts from institutions. Findings like these patterns in Table 2 drive one of this paper's main ideas, that financial, judicial, and labor market institutions also substantially affect location choices of clean versus dirty industries.

Table 2 allows a couple other interpretations. One sees how changing national institutions from the tenth to the ninetieth percentile of institutional quality affects emissions. I calculate a country's baseline environmental quality as $Z_i = \sum_{j,s} X_{ijs} Z_s$, and counterfactual environmental quality as

$$Z' = \sum_{j,s} [X_{ij,s} Z_s + e^{\hat{\alpha}^C Z_i [E^e_{0.9} - E^e_{0.1}]} Z_s] \tag{10}$$

Here $\hat{\alpha}$ is from equation (9), $E^e_{0.9}, E^e_{0.1}$ are the ninetieth and tenth percentile of institutional quality, and I calculate the proportional change in a country's pollution due to changing institutions as $(Z'_i/Z_i - 1)$.[9] The fitted effect row at the bottom of Table 2, Panel B, columns (5) and (6), suggests that this counterfactual would decrease a country's emissions by about 25 percent. This large decline would imply that institutions substantially drive environmental quality.

This calculation requires strong caveats. It includes only analyzes traded manufacturing goods. It assumes other sources of technology, factors, and determinants of specialization are fixed, and that

[9] I measure the tenth percentile of institutions as the mean institution index for countries between the fifth and fifteenth percentile of that index, and the ninetieth percentile as the mean institution index for countries between the eighty-fifth and ninety-fifth percentile of that index.

institutions have log-linear effects. It also comes from a partial equilibrium calculation, which abstracts from changes in wages or prices. The quantitative model in Section 6 helps relax these assumptions.

A second interpretation of Panel B of Table 2, column (10), recognizes that the coefficient on institutions is 80 percent as large as the tariff coefficient. Globally, one standard deviation of tariffs is 9 percentage points weighted by trade value and 15 percentage points unweighted. Hence, for an industry one standard deviation cleaner than average, improving institutions by one standard deviation would increase exports by about the same amount as decreasing tariffs by 7 to 12 percentage points. This would be similar to ending a trade war or granting a country Most Favored Nation status, and implies that institutions have effects on clean industries comparable to enormous changes in trade policy.

4.3 Alternative Research Designs

I now discuss alternative versions of these estimates. Table 3, Panel A, reports baseline estimates controlling for institutions, factors, environmental regulation, and tariffs.

Instrumental Variables Estimates

Omitted variables could bias estimates of the comparative advantage equation (9). Countries with stronger institutions could have other characteristics which affect trade and are correlated with the institutions×clean industry interaction, conditional on the controls. For example, if countries with mild climates have stronger institutions, but mild climates directly improve productivity in clean industries, then equation (9) would overstate the comparative advantage that institutions provide in clean industries. Measurement error is a potentially secondary concern. Although institutions are difficult to measure well, I examine many separate types of institutions, and aggregating across multiple measures of institutions may help average out measurement error in each individual series. Additionally, measurement error in identifying clean industries is not a major concern, since the pollution measures reflect good quality plant-level emissions data aggregated across multiple air and water pollutants.

A related story would be that structural transformation from agriculture to manufacturing then services improves a country's institutions, and also changes specialization between clean and dirty industries. In this story, the stage of a country's development and its level of structural transformation are omitted variables in equation (9). To help rule out the possibility of associated bias, I use predetermined instrumental variables from over a century ago in a single cross-section of countries.

While I report these instrumental variables (IV) estimates given the possibility of omitted variables or other issues like measurement error, ex ante evidence does not provide reason to expect overwhelming or systematic bias, and I interpret the IV estimates more as a sensitivity analysis than main result. Nunn (2007) finds that IV estimates of the overall comparative advantage of institutions, using legal origins interactions as instruments, are moderately larger than ordinary least squares estimates. Many trade papers with related methods do not report estimates instrumenting for country characteristics, potentially due to the sense that econometric problems which IV would address are not first-order in related settings (Romalis 2004; Levchenko 2007; Chor 2010; Cuñat and Melitz 2012; Manova 2013). Additionally, using country×industry interactions may decrease the scope for omitted variables bias—to create bias, an omitted variable must not only correlate with institutions, but correlate with institutions particularly for clean industries, and conditional on factor endowments and trade policy.

The IV estimates have the following first-stage:

$$E_i I_s = \sum_o \alpha_o^F L_{i,o} I_s + \sum_f \beta_f^F E_i^f I_s^f + \pi^F R_i Z_s + \gamma^F t_{ij,s} + \zeta_{j,s}^F + \eta_{ij}^F + \epsilon_{ij,s}^F \tag{11}$$

I instrument the interaction of a country's institutions and an industry's dependence on institutions, $E_i I_s$, with the interaction of indicators for the origin o of a country's legal system and an industry's clean index. Here L_i^o is an indicator for whether the legal system of exporter i originates in country o, measured from La Porta et al. (2012). Equation (8) represents the structural or second stage. The estimates include four interactions, for British common law, French civil law, German civil law, or Socialist legal origin (Scandinavian civil law is the reference category). I also report estimates that use settler mortality or population density in the year 1500 as instrumental variables (IV) for institutions, and estimates that use multiple instruments to separate the roles of property rights institutions that constraint executive power versus institutions improving contract security (Acemoglu and Johnson 2005).

Legal origins are widely used as instruments in research on institutions, with the motivation that legal origins determine contract enforcement, judicial quality, and financial systems (Djankov et al. 2003; Acemoglu and Johnson 2005; Lerner and Schoar 2005; Nunn 2007). Scholars have debated the interpretation and importance of a country's legal origins (La Porta, Lopez de Silanes and Shleifer 2008). Used as an instrument, I assume that legal origins predict institutions (testable with the first stage); I also assume that legal origins, interacted with the clean index, affect trade only through the interactions of institutions and the clean index, conditional on the other controls. The estimates using settler mortality or year 1500 population density involve analogous assumptions.

Appendix Table 3 shows the first-stage estimates. Columns (1) through (4) study comparative advantage in all industries, which provides a first stage for equation (8); columns (4) through (8) examine comparative advantage in clean industries, which provides a first stage for equation (9). Legal origins provide strong instruments, with first-stage F statistics for the institutions index of 164 to 214. The instruments are also strong for each type of institutions individually. Relative to Scandinavian legal origins (the reference category), British legal origins predict the strongest institutions.

Table 3, Panel B, shows second-stage instrumental variables (IV) estimates that use legal origins interactions as instruments. While some IV estimates exceed corresponding OLS estimates, for the key estimate in column (8), results are similar, with an OLS estimate of 0.40 (0.003) and IV estimate of 0.048 (0.005). Given the complexity of measuring institutions, measurement error is a plausible explanation for why some IV magnitudes modestly exceed OLS magnitudes. Qualitatively, however, the instrumental variables and OLS regressions imply similar conclusions.

Panel Data Estimates

I use 1996-2015 panel data to test if clean exports increase in countries where institutions improve:

$$lnX_{ij,sy} = \alpha^P E_{i,y} Z_s + \sum_f \beta_f^P E_{i,y}^f I_s^f + \zeta_{j,sy}^P + \eta_{ij,y}^P + \epsilon_{ij,sy}^P \tag{12}$$

Here trade flows X, institutions E, factors E^f, and the fixed effects ζ and η vary by year y. I assume the clean industry index Z, factor intensities I_s^f, and tariffs t are time-invariant, due to limited data availability for the full panel. The comparative advantage parameter α^P is identified from differences in institutional quality within a country, interacted within an industry's clean index. One motivation for these estimates is that a country's institutions could correlate with time-invariant country characteristics, such as geography, which differentially encourage specialization in clean industries.

I also estimate a long-differenced version of equation (12), with the first and last years of data. This may provide a more accurate estimate than the full panel regression for two reasons. Because institutions may be measured with error, panel estimates like equation (12) can exacerbate attenuation bias due to measurement error (Griliches and Hausman 1986). Additionally, institutions can change gradually, and trade may respond gradually to institutions. Cross-sectional estimates like equation (9) obtain a long-run relationship between institutions and trade, while panel data estimates like equation (12) estimate the short-run relationship. The long-differenced estimate obtains medium-run estimates.

Although a country's institutions have path dependence, the mean country has large changes in institutions over 20 years, which suggests that changing institutions has scope to affect pollution. Between 1996 and 2015, the absolute value of institutions in the mean country changed by half a standard deviation.[10] Institutions improved in about two-thirds of countries and worsened in a third of countries. The rate of change was slightly lower for judicial institutions and slightly higher for labor market institutions. For comparison, in the mean country between 1996 and 2015, the absolute value of capital and skill endowments changed by a similar amount—0.6 and 0.4 standard deviations.

Figure 3 Panel C shows panel graphs relating changes in trade over 20 years to changes in institutions. For example, Rwanda had among the most rapid improvements in institutions in this period, while Egypt

[10]This statistic reports the mean across countries of $|E_{i,2015} - E_{i,1996}|$,where $E_{i,y}$ is a measure of institutions or factor endowments in country i and year y. For comparability with most of the paper, these values are normalized to have mean zero and standard deviation one in the year 2012.

had among the most rapid deterioration of institutions. This graph divides countries into two groups: countries where institutions improve and countries where institutions worsen. For each industry, I calculate the share of global exports from each group of countries in 1996 and in 2015. I then plot a nonparametric regression of the change over time in these shares for each country×industry.

Figure 3 Panel C shows that countries where institutions improve have faster export growth in all industries, since the solid blue line lies above the x-axis. Countries where institutions worsen have slower export growth in all industries, since the dashed red line lies below the x-axis. The slopes show that countries where institutions improve disproportionately increase exports in clean industries. Countries with improving institutions increase their share of world exports for clean industries by about 20 percentage points. Those countries increase their share of world exports for the dirtiest industries by only 1-2 percentage points. Countries where institutions worsen hardly change their share of world exports in dirty industries, but substantially decrease their export share in clean industries.

Table 3, Panels C and D, exploit panel variation in institutions, capital, labor, and other variables within a country and over 20 years, corresponding to equation (12). Panel C uses all years of data. If institutions are measured with error, panel estimates can exacerbate attenuation bias (Griliches and Hausman 1986). Panel D therefore includes only the first and last years of data.

The panel data estimate obtains precise results, with smaller magnitudes in the full panel but larger magnitudes in the long-differenced estimates. In column (8) of Table 3, Panels C and D, the comparative advantage that institutions provide in clean industries is 0.040 (0.003) in the baseline estimates, 0.013 (.001) in the full panel estimates, and 0.061 (0.008) in the long-differenced estimates. The smaller magnitude of the full panel versus long difference is consistent with measurement error in institutions. It is also consistent with the possibility that trade responds gradually to institutions.

Cross-State, Intranational Institutions

I also compare institutions across states within a single country, India. Some determinants of specialization vary across countries in ways that are difficult to observe. Comparing across states within a country helps address that challenge, since it effectively holds other national variables fixed. India is a useful setting for such an analysis since India's institutions vary across states and existing work has measured them. I use production data to estimate the following test:

$$lnX_{i,s} = \alpha^I E_i I_s + \sum_f \beta_f^I E_i^f I_s^f + \pi^I R_i Z_s + \eta_i^I + \zeta_s^I + \epsilon_{i,s}^I$$

Here $X_{i,s}$ represents the gross output of industry s in state i. I analyze gross output rather than bilateral trade here since this is what India's Annual Survey of Industry reports.

Table 3, Panel E, estimates comparative advantage due to institutions across states in India. Columns

(1)-(4) find that judicial and labor institutions, though not financial institutions, provide comparative advantage overall. Columns (5) through (8) estimate that these institutions provide comparative advantage in clean industries. The magnitude of the overall comparative advantage of institutions in column (4), and the comparative advantage that institutions provide in clean industries in column (8), are both moderately larger than the global estimate from Panel A. The global and intra-national India estimates differ in several ways, including the use of trade versus production data and using different measures of institutions. While this makes it difficult to provide a perfect apples-to-apples comparison, the magnitudes of baseline estimates in Panel A versus these India estimates in Panel E at least do not support the concern that the global estimates of institutions' comparative advantage is due to unobserved country-level variables that are correlated with institutions.

4.4 Sensitivity Analyses

Appendix Table 4 obtains similar estimates of the comparative advantage equations (8) and (9) using different measures of environmental regulation. In Row 1, I transform each measure of environmental regulation to equal a country's percentile among all countries with non-missing values of that measure of regulation, and I then average percentiles across measures of regulation within a country. In row 2, I measure environmental regulation in each country as the mean of the z-scores of each of the eight measures of environmental regulation. I use these aggregates in rows 1 and 2 because they, unlike principal components, are defined even when a country is missing some of the underlying measures of environmental regulation. Rows 3-10 examine one measure of environmental policy per row. Across these ten different ways of measuring environmental regulation, these county institutions×clean industry interactions have coefficients between 0.03 and 0.06 and are statistically distinct from zero at 99 percent confidence. The estimates of the importance of regulation itself are more variable across measures of regulation, consistent with the rationale for aggregating across these measures in the main results.

Appendix Table 5 obtains qualitatively similar estimates from different measures of each institution; Appendix A.1 describes data sources. I consider three alternative measures of financial institutions, four alternative measures of judicial institutions 5 alternative measures of labor market institutions, and nine estimates comparing measures of property rights institutions, one based on whether a system constrains executive power and one based on the effectiveness of contracting institutions. In line with Acemoglu and Johnson (2005), I show institutions on their own and instrumented by colonial settler mortality, population density in the year 1500, legal origins, or combinations of the three.

In column (1) of Appendix Table 5, most estimates imply that institutions provide a source of comparative advantage. A couple estimates which simultaneously control and instrument for constraint on the executive and contracting institutions have more sensitive results, reflecting the difficulty of separating comparative advantage due to these correlated interpretations of property rights. In column (2), most measures of institutions provide comparative advantage in clean industries. Estimates in rows 13-22 seeking to unbundle institutions suggest that contracting institutions, more than institutions constraining executive power, drive comparative advantage in clean industries, which makes sense and fits with the interpretation of judicial institutions in the rest of the paper.

Appendix Table 6 uses other data sources and econometric assumptions. I report estimates controlling for all three types of institutions at once; including non-manufacturing goods industries;[11] replacing the bilateral fixed effects with bilateral distance, common language, and other standard gravity variables from CEPII; using PPML; using Exiobase; measuring pollution in the entire value chain via the Leontief Inverse matrix; and replacing the continuous clean index with an indicator for not being among the dirtiest 10 percent of industries. The "dirtiest industries" indicator follows the Pollution Havens Hypothesis literature, which typically focuses on the dirtiest set of industries rather than using a continuous clean industry index. The qualitative patterns across these different estimates are similar. The interaction term for strong country institutions×clean industry ranges from 0.04 to 0.06 and is generally precise. The largest point estimates are from using PPML and Exiobase.

I also discuss how institutions affect clean production techniques within an industry. I primarily study how institutions affect the composition of production between clean and dirty industries. Institutions could affect a country×industry's clean index, though with ambiguous sign. For example, better institutions could move firms from clean inputs like labor towards dirtier inputs like intermediates (e.g., energy), or could make firms substitute from dirtier to cleaner intermediate goods.

Because interacting industry intensities and country endowments cannot test how institutions affect technique within an industry, I simply relate cross-country differences in the clean index within industries to cross-country differences in institutions, using the following regression:

$$Z_{is} = \alpha^T E_i + \sum_f \beta_f E_i^f + \pi R_i \eta_s + \mu_s + \epsilon_{is} \tag{13}$$

Because this equation uses pure cross-country comparisons, it requires the strong identifying assumption that conditional on factor endowments and environmental regulation, institutions are independent of other determinants of a country×industry's clean index. Any estimate using this assumption requires stronger caveats than estimates in the rest of the paper. Given this important caveat, Appendix Table 6, row 9, estimates an imprecise zero effect of institutions on clean production techniques for a country×industry. The negative sign would suggest that countries with better institutions tend to have less clean production techniques within an industry, although the wide confidence interval fails to reject

[11] This estimate adds agriculture and mining, the two tradable goods industries besides manufacturing. The limited difference in the number of observations between rows 1 and 3 is because agriculture and mining have far fewer 6-digit NAICS industry codes than manufacturing, and they tend to have fewer trading partners.

zero or moderate magnitudes. Overall, I conclude that this paper's setting has power and a research design that are not ideally suited to test the effect of institutions on clean production techniques within an industry, which I leave as an important question for future work. Hence the remainder of the analysis maintains the paper's focus on effects of institutions through comparative advantage.

5 Explanations

The previous results provide evidence that institutions provide comparative advantage in clean industries but do not explain why. Investigating why institutions are important to clean industries is important on its own and hepls increase the plausibility of results in the earlier sections. I now use information on many industry characteristics to provide some insight. These are primarily variables relevant to political economy and found to influence trade policy (Rodrik 1995; Shapiro 2021).

I first regress an industry's clean index on other industry characteristics, one at a time:

$$Z_s = \rho_0^W + \rho_1^W W_s + \epsilon_s^W \tag{14}$$

This comparison indicates which industry characteristics W are correlated with being clean. I then adapt equation (2) by assessing how controlling for one industry characteristic changes the association of the clean index with an industry's dependence on institutions:

$$Z_s = \rho_0^{IW} + \rho_1^{IW} I_s + \rho_2^{IW} W_s + \epsilon_s^{IW} \tag{15}$$

The additional control W_s varies by regression. I investigate how each control W_s changes the association of institutional dependence and the clean industry index. Finally, I adapt equation (9) by controlling for the interaction of one additional industry characteristic W_s with a country's institutional quality E_i:

$$lnX_{ij,s} = \alpha^W E_i Z_s + \alpha^W E_i W_s + \sum_f \beta_f^W E_i^f I_s^f + \pi^W R_i Z_s + \gamma^W t_{ij,s} + \zeta_{j,s}^W + \eta_{ij}^W + \epsilon_{ij,s}^W \tag{16}$$

Table 4, column (1), shows that clean and dirty industries differ on many dimensions. Clean industries have more specialized, sophisticated, and skilled inputs. Specifically, clean industries have lower cost shares of energy and raw materials, more differentiated products (higher inverse export supply elasticity), have lower shipping costs, and are less upstream. An industry's raw materials share and shipping cost have the strongest associations with the clean index.

Table 4, columns (2) through (4), assess whether these characteristics account for the relationship between an industry's dependence on institutions and its clean index, as in equation (15). They show that differentiated, processed, and downstream industries are clean and depend on institutions. The most important industry characteristics here are the industry's raw materials share, its upstreamness, its workers' education, and its product shipping costs. No one industry characteristic alone fully accounts for the association between an industry's institutional dependence and its clean index, though all these characteristics together do, as indicated by the small magnitudes in the final "all at once" row.

Column (5) of Table 4 estimates equation (16). The last row of Table 4 controls for all these variables at the same time. No single variable completely accounts for the comparative advantage that strong institutions provide in clean industries. An industry's raw materials share accounts for a fifth of the comparative advantage of clean industries; the shipping cost accounts for half; and including all variables together account for about 40 percent of this comparative advantage.

In studying trade policy and CO_2, a single industry characteristic, upstreamness, primarily accounts for the lower trade protection of dirty industries (Shapiro 2021). This is not the case here—many variables together account for the reason why countries with strong institutions specialize in clean industries. The most important variables reflect the idea that clean industries are specialized, skilled, and downstream, or in one word, complex. One possible reason for the difference between the analysis of trade policy and CO_2 versus this paper is that the local pollutants studied here depend on end-of-pipe pollution control technology, which varies substantially and idiosyncratically across industries based on many forces. CO_2, by contrast, has no economically viable end-of-pipe abatement technology, and depends only on energy inputs, which vary more systematically across industries.

Given the many hypothesis tests in Table 4, Appendix Table 7 reports a version of p-values adjusted for multiple hypothesis testing. Formally, Appendix Table 7 reports the sharpened False Discovery Rate q-value from Anderson (2008), which can be higher or lower than the p-value from a regression. The qualitative conclusions and patterns of statistical significance are similar between the main results in Table 4 and the results adjusted for multiple inference in Appendix Table 7.

6 Counterfactual Institutions: Model-Based Estimates

The previous sections find that institutions provide comparative advantage in clean industries and that industry complexity helps explain why. I now use a model which incorporates estimates from previous sections to quantify how improving institutions affects environmental quality through comparative advantage. This section does not introduce new tools, but instead combines leading models with estimates of the previous sections to enable analysis of specific counterfactual changes in institutions.

The model has typical features—multiple industries, intermediate goods, input-output links, trade imbalances, tariffs, and pollution emission rates for each country×industry, in all sectors of the economy. Because many model details are common in the structural gravity literature, I describe them in Appendix D. Here I highlight key features and focus on aspects which differ from a standard trade setting.

It is feasible for this model to analyze social welfare, accounting for both changes in environmental quality and the gains from trade. I do not report social welfare calculations, however, given the limited quality of estimates available for the damages due to pollution emissions in countries around the world.[12]

Each country has a representative agent who maximizes utility that is a constant elasticity of substitution (CES) aggregate across varieties and Cobb-Douglas across sectors. The representative agent experiences disutility from pollution. This is a multi-country, multi-sector Ricardian trade model of perfect competition (Eaton and Kortum 2002) —buyers source a variety from the lowest-price producer and trade faces iceberg trade costs and tariffs. Production is Cobb-Douglas in labor and intermediate goods, which use inputs from all sectors as dictated by an input-output table. Productivity has a Fréchet distribution with location parameter $T_{i,s}$ and dispersion parameter θ_s. I describe $T_{i,s}$ as each country×industry's technology or productivity level. Given the absence of firm-level emissions data in most countries, and in order to have a single elasticity governing the response of pollution to institutions, I assume firms within a country×industry have the same emissions intensity.

I interpret institutions as changing country×industry productivity in potentially every sector, including non-tradable goods. Equation (5) implies that reforming institutions proportionally changes productivity for exporter i and industry s via

$$\hat{T}_{i,s} = exp\left\{\alpha I_s(E_i^{'} - E_i)\right\} \tag{17}$$

To estimate (17), I use estimates of α from equation (8), data on an industry's dependence on institutions I_s and a country's baseline quality of institutions E_i, and then I choose $E_i^{'}$ to define a counterfactual.

Country i's baseline pollution emissions are

$$\mathcal{E}_i = \sum_s \frac{\gamma_{i,s} R_{i,s}}{c_{i,s}}$$

where $\gamma_{i,s}$ measures the baseline units of pollution emitted per real unit of output, $R_{i,s}$ describes country×sector revenue, and $c_{i,s}$ is the unit cost function. Pollution depends on the ratio $R_{i,s}/c_{i,s}$ since it reflects units rather than value of sectoral output. The model can accommodate changes in pollution intensity $\gamma_{i,s}$ due to changes in institutions. Following the technique effect results discussed

[12] Quantifying the willingness to pay for environmental quality requires a geographically resolved intra-national model of how each ton of emissions affects air quality within a country; how ambient air quality affects mortality and other health and welfare outcomes; and finally attaching the value of a statistical life or other valuation metrics. Several integrated assessment models provide information on these channels for the US (Muller and Mendelsohn 2009; Shapiro and Walker 2023), from information on the spatial distribution of emissions within a country, wind patterns, concentrations of other pollutants and atmospheric conditions that contribute to pollution (e.g., solar radiation creates ground-level ozone pollution), and the spatial location of population by age. While pieces of these models can be imputed for many countries, the spatial distribution of emissions within a country others are difficult to model well for each country around the world. In the US, for example, the social cost of emitting a unit of pollution can vary a thousand-fold between densely and sparsely populated areas (Muller and Mendelsohn 2009). This complexity distinguishes "local" air and water pollutants, the focus of this paper, from global greenhouse gases that previous research has analyzed (e.g., Shapiro (2021)).

near the end of Section 5, however, I assume that the pollution intensity $\gamma_{i,s}$ of exporter i in industry s is invariant to counterfactual changes in institutions. If stronger institutions generated cleaner production techniques, this assumption would tend to understate institutions' environmental benefits.

I study a competitive equilibrium. Consumer utility maximization implies the gravity equation (3). Total country×sector expenditure equals the sum of spending on final and intermediate goods, accounting for revenues from fixed trade deficits and tariffs. I study counterfactual policies by expressing variables in changes, i.e., using exact hat algebra (Dekle, Eaton and Kortum 2008). I focus on counterfactuals which change technology in certain country×industry pairs due to changes in institutions. The change in pollution due to changing institutions is

$$\hat{\mathcal{E}}_i = \frac{\sum_s (\hat{R}_{i,s}/\hat{c}_{i,s})\mathcal{E}_{i,s}}{\sum_s \mathcal{E}_{i,s}} \tag{18}$$

where $\mathcal{E}_{i,s}$ is the baseline observed pollution for a country×sector. Equation (18) says that the proportional change in a country's pollution is the sum across industries of baseline pollution from an industry times the industry's change in real output, all divided by the country's baseline pollution.

Counterfactuals and Results

I study three counterfactuals. The first sets all regions to have the same quality of institutions, equal to the global mean. This provides a benchmark to think about the signs and magnitudes of more realistic changes in institutions. The second counterfactual takes regions with below-median institutional quality and improves their institutions to the level of North America, the region with the strongest baseline institutions. The third counterfactual takes Latin America, the region with the lowest-quality institutions, and improves its institutions to match those of North America.

Table 5 shows effects of these counterfactuals. Panels A through C analyze each counterfactual. Each row shows estimated effects for one region. The last row of each panel shows the global total. Column (1) shows baseline data on institutional quality. Column (2) shows the change in institutional quality chosen to define the counterfactual. Column (3) shows the model-estimated percentage change in emissions due to the counterfactual. Column (4) shows the percentage change in emissions per dollar of output due to the counterfactual. Columns (5) through (7) describe the counterfactual's effect on the share of output from three groups of industries—the dirtiest, middle, and cleanest third.

Panel A of Table 5 shows that the first counterfactual, which equalizes institutions across regions, also helps equalize pollution across regions. Column (1) shows that Northern Europe, North America, and Pacific countries like Japan and Korea have the strongest baseline institutions. Column (2) shows that in this counterfactual, institutions in these regions worsen the most. Column (3) shows that this counterfactual increases pollution in these regions. This counterfactual increases emissions in Northern

Europe and decreases emissions in Latin America, both around 10 percent. Columns (5) through (7) show that these changes come from reallocating production between clean and dirty industries.

Panel B of Table 5 considers the second counterfactual, which improves institutions in regions with below-median institutions to equal the mean quality of institutions for regions with above-median quality institutions. Column (2) shows that this improves institutions in targeted regions by one to two standard deviations. Column (3) shows that this counterfactual decreases emissions in targeted regions by 3 to 13 percent. In regions where institutions remain unchanged, this counterfactual increases pollution emissions by 3 to 4 percent. The second counterfactual increases pollution in regions where institutions do not change because it works through comparative advantage. As institutions improve in Latin America and Eastern Europe, those regions gain comparative advantage in clean industries. This leads some clean production to move to these targeted regions, and some dirty production to move elsewhere.

Table 5, Panel C, analyzes the third counterfactual, where institutions in Latin America improve to match those of Northern Europe. This counterfactual decreases pollution emissions by nearly 20 percent in Latin America. This counterfactual also makes clean industries move to Latin America and dirty industries move elsewhere. Emissions rise by up to 1 percent in regions outside Latin America, due to comparative advantage-driven reallocation of clean and dirty production.

Appendix Table 8 shows effects of these counterfactuals on each air pollutant in Exiobase. All counterfactuals decrease all pollutants globally. Particulate matter smaller than 2.5 micrometers ($PM_{2.5}$) decreases more than non-methane volatile organic compounds (NMVOCs) globally, perhaps in part because more of NMVOCs comes from transportation, which is less traded.

These counterfactuals primarily change pollution by reallocating dirty production between regions, but Table 5 shows that they decrease total global emissions. The second counterfactual, for example, decreases global emissions by 4 percent. The global decreases occur in part because regions with strong baseline institutions have low baseline emission rates. Thus, reallocating one dollar of dirty production from countries with weak to strong baseline institutions tends to decrease total global production.

While most research on greenhouse gases analyzes global total emissions, I am not aware of prior analysis of the global sum of local air pollution emissions. In part this is because greenhouse gases create the same climate damages regardless of where they originate, while damages from local air pollutants vary by location of emissions since they depend on population density, wind, and many other variables.

The paper could conclude here, and has already used several methods and datasets to test its main hypothesis. An important consideration here, however, is that this paper's main findings appear to conflict with prior research. Research on trade and the environment in many countries finds that the technique of producing goods within an industry, rather than the composition of output across industries, accounts for most aggregate patterns of environmental quality (Levinson 2009; Grether, Mathys and de Melo 2009; Shapiro and Walker 2018; Brunel 2016; Copeland, Shapiro and Taylor 2022). This finding of prior research suggests that the composition of production across industries plays only a modest role in explaining global patterns of environmental quality. How can we reconcile this finding from prior research with the finding from this paper that cross-country differences in the composition of production, driven by institutions, play an important role in explaining global patterns of environmental quality?

The next section highlights an underappreciated feature of prior work—prior decompositions look within a country and over time, and make no cross-country comparisons. For example, existing work studies the extent to which scale, composition, and technique explain the change in US pollution emissions between 1990 and 2008, and provides similar decompositions for other countries. The next section adapts this decomposition used in prior work to instead ask, for example, to what extent scale, composition, and technique explain the difference in pollution emissions from India versus the US. In other words, the next section performs a cross-country, cross-sectional decomposition, whereas prior work has reported a within-country, time-series decomposition. The decomposition in the next section does not distinguish the role of institutions versus other forces in driving composition. It does, however, ask whether there is scope for any driver of comparative advantage, including institutions, to substantially affect environmental quality, and thus could help reconcile the results of the paper up to this point with existing literature which finds little role for composition.

7 Decomposing Scale, Composition, and Technique

I apply the following decomposition. Let $\mathcal{E}$ denote a country's total pollution emissions, which equal the sum of industry-specific emissions $\mathcal{E}_s$ across all industries in the economy. This includes but is not restricted to manufacturing, agriculture, utilities, and household production. We treat country as the unit of observation in part because Exiobase and other global multi-region input-output tables lack sub-national geography on where within a country emissions and economic activity occur. At the same time, global emission and pollution rates reach especially high levels in large cities and near population centers (UNEP 2016), so it is likely that these emissions data reflect pollution that affects households.

An industry's emissions $\mathcal{E}_s$ equal the product of sales x_s and emissions intensity, $e_s = \mathcal{E}_s/x_s$. We can write an industry's sales as $X\kappa_s$, where κ_s is the share of the economy's sales from industry s:

$$\mathcal{E} = \sum_s \mathcal{E}_s = \sum_s x_s e_s = X \sum_s \kappa_s e_s \tag{19}$$

Totally differentiating then dividing by $\mathcal{E}$ yields

$$\frac{d\mathcal{E}}{\mathcal{E}} = \frac{dX}{X} + \frac{d\kappa}{\kappa} + \frac{de}{e} \tag{20}$$

The first term on the right of (20) represents scale, the second is composition, and third is technique.

Research typically takes equation (20) to data by measuring emission rates e_s for each industry in a reference year, then projecting onto future years within a country. I instead take industry emission rates in a reference country r. I project those rates onto the same industry in other countries to distinguish scale, composition, and technique effects. I implement this comparison for each country i separately:

$$Scale_{i,r} = \frac{\sum_s x_{is}}{\sum_s x_{rs}} \tag{21}$$

$$Composition_{i,r} = \frac{\sum_s \kappa_{is} e_{rs}}{\sum_s \kappa_{rs} e_{rs}} = \frac{\sum_s \kappa_{is} e_{rs}}{Z_r / X_r} \tag{22}$$

$$Technique_{i,r} = \frac{\sum_s \kappa_{is} e_{is}}{\sum_s \kappa_{is} e_{rs}} = \frac{Z_i / X_i}{\sum_s \kappa_{is} e_{rs}} \tag{23}$$

Here r indexes a reference country, x_{is} represents the gross output of focal country i in industry s, κ_{is} represents the share of country i's gross output from industry s, and e_{is} are emissions per dollar of gross output. In presenting estimates of equations (21) through (23), I subtract one, so the results can be interpreted as the percentage change relative to the reference country. Appendix C derives these equations from those used in prior literature that compares within a country and over time.

The scale effect in (21) equals the difference in gross output between country i and reference country r. This describes how emissions would change if country i had the total output of country r, but the composition of output across industries and emissions per unit output within an industry were fixed.

The composition effect in equation (22) equals the difference in emission rates between countries i and r due to their difference in the share of output κ from each industry. Composition weights output shares by the reference rates, e_{rs}. I use these weights since they are common in the literature comparing environmental change within a country and over time (Appendix C).

Technique equals the difference in emissions between countries i and r due to their difference in emission rates e from each industry. Equation (23) uses weights from the focal country κ_{is} for consistency with the literature (Appendix C). Thus, the technique effect can be interpreted as holding composition fixed at the focal country level κ_{is}, then comparing the difference in emissions due to differences in technique between the focal and reference countries (e_{is} versus e_{rs}). Again, below I report the distribution of results from possible alternatives. To help assess the relative importance of composition versus technique overall, I report the absolute value of the technique effect and the absolute value of the composition effect.[13] To compare them, I present the ratio $|Composition|/(|Composition| + |Technique|)$.

Consider the example of sulfur oxides emissions in India and the US. Using Exiobase, the scale effect

[13] Existing research focuses on the composition and technique effects in levels, not absolute values. The absolute values here are useful because they summarizes the importance of these effects in explaining cross-country differences in pollution, even if some relative comparisons are positive and others are negative. For example, if the composition effect increased pollution in half of countries relative to the US and decreased pollution in half of countries relative to the US, and both by similar amounts, then the mean value of the composition effect between the US and other countries would be zero, but the absolute value of the composition effect would not be.

from (21) indicates that India produced 87 percent less output than the US. Sulfur oxides emissions, however, were 12 percent higher in India than the US. The composition effect from equation (22) indicates that India emitted 162 percent more sulfur oxides than the US did because a larger share of India's output comes from dirtier industries. The technique effect from equation (23) indicates that India produced 216 percent more pollution than the US because a given industry emits relatively more pollution per dollar of gross output in India than in the US does. Thus, although India produces less output than the US economy (scale), it emits more sulfur both because it is more concentrated in polluting industries (composition) and because a given industry emits more pollution in India (technique). Here, composition accounts for 43 percent (=162/(162+216)) of the composition+technique total.

Table 6 provides such comparisons for all countries and pollutants, with the US as reference. Row 1 shows that the mean country has 72 percent lower total pollution emissions than the US. Row 2 shows that the mean country has 90 percent lower gross output than the US does. Row 3 shows that the composition of output across industries in the mean country increases emissions 175 percent relative to the US, i.e., most countries produce dirtier types of goods than the US does. Row 4 shows that the technique effect for the mean country does not substantially change emissions relative to the US, i.e., some countries use cleaner techniques and others dirtier, but the mean is comparable. While some countries have a positive composition effect (dirtier than the US) and others negative, Row 5 shows that the composition effect in the mean country changes emissions relative to the US by 176 percent. Row 6 shows that in the mean country, the absolute value of the technique effect increases emissions relative to the US by 47 percent.[14] Comparing Rows 5 and 6 indicates that in absolute values, the composition effect accounts for 79 percent (=176/(176+47)) of the combined composition and technique effect magnitudes.

Figure 4 describes the distribution of the ratio $|Composition|/(|Composition|+|Technique|)$ across all possible reference countries, separately by focal country. For example, comparing the US to India creates one data point, and the US versus France is another. Each observation underlying Figure 4 is a country pair rather than a country because equations (21), (22), and (23) involve comparing a reference to a focal country (e.g., the US versus India).

Figure 4 finds that across all country pairs, composition accounts for slightly more of cross-national differences in pollution than technique does. The distribution is roughly a truncated bell-curve shape. The mean and median composition share are about 0.70. No mechanical reason makes these shares near half. Given prior literature, one might expect technique to account for most of this difference.

Why does Figure 4 find a large role for composition, while prior literature finds a larger role for technique? One reason is that Figure 5 compares across countries and within a time period, while prior literature looks within a country and over time. A deeper explanation is that a country's institutions

[14] Row 4 shows that the mean technique effect is similar to the US, but Row 6 shows that many countries have a technique effect either higher or lower than the US (i.e., the US and other countries have the same means, but larger differences in absolute value).

and factor endowments rarely change rapidly. This makes the composition effect less important for explaining change within a country and over time. It is one reason the legal origins, settler mortality, and year 1500 population density instruments strongly predict institutions today. Environmental policy can change more quickly, which may make the technique effect more important for explaining change within a country over time. A second explanation is that technique depends on a country's absolute emissions rate, while composition depends on countries' relative comparative advantage. If environmental policy and institutions strengthen similarly in all countries over time, technique could matter more in the time series but composition could matter more in the cross section. I emphasize that because these are decompositions and not regressions, the aforementioned findings do not reflect differences in regression assumptions about omitted variables bias, or measurement error, or other forces that differ between cross section and panel data regressions, but instead represent some forces (potentially including institutions) which make composition more important in the cross section across countries than time series within a country to explain the global distribution of environmental quality.

This section's cross-country decomposition reach out of sample. In the literature's application of this decomposition to a country's time series, endowments like factors and institutions change gradually, while policies or other shocks may change more rapidly. Because the decomposition here compares two arbitrary countries in a cross-section, endowments including institutions differ considerably between focal and comparison countries. For example, this decomposition does not imagine that plausible short-term policies could transform India's composition to match that of the US. At the same time, comparing the composition versus technique of industries between countries can provide useful insights about potential mechanisms for realistic counterfactuals. For example, the influential Environmental Kuznets Curve literature (Grossman and Krueger 1993) makes cross-sectional comparisons across countries. While the Environmental Kuznets Curve literature motivated discussions of scale, composition, and technique, ensuing decompositions to date have focused on the time series rather than the cross section.

8 Conclusions

Existing research highlights three forces that help explain international patterns of environmental quality—weaker environmental regulation in some countries increases their pollution (the Pollution Havens Hypothesis); greater capital endowments in some countries attract capital-intensive, dirty industries there (Heckscher-Ohlin); and trade openness increases per capita GDP, which has nonlinear effects on the concentration of polluting industries (the Environmental Kuznets Curve).

This paper proposes and evaluates an additional explanation for international patterns of environmental quality. Institutions improve international environmental quality through comparative advantage. Clean industries depend on strong financial, judicial, and labor market institutions to operate efficiently. Clean industries thus disproportionately locate in countries with strong institutions. Quantitatively, institutions have comparable importance as environmental policy in explaining international specialization of dirty industries. Estimates indicate that if countries with the world's weakest institutions instead had some of the world's strongest institutions, their pollution emissions would fall by up to 20 percent. I find an important role for institutions across countries, over two decades of institutional change within countries, and when instrumenting institutions with a country's legal origins.

This paper's main conclusions do not point to a specific environmental or trade policy that improves environmental quality. Hence, the goal of this paper is not to provide a new perspective on the welfare consequences or optimal design of environmental or trade policy. Instead, this paper highlights how policy reforms usually thought unrelated to the environment, such as judicial reforms that improve contract enforcement, or financial reforms that improve credit markets, or labor market flexibility reforms, can improve national environmental quality through attracting clean industries.

If environmental policy around the globe was optimal, e.g., if every country had Pigouvian taxes on all air and water pollutants, this paper's findings would not change the national benefits of institutions. To the extent that environmental policy is less stringent than optimal, especially in developing countries, this finding strengthens the case for policies that improve institutions in developing countries, since it shows that such reforms help address environmental externalities. While a Pigouvian tax is first-best, in many settings political economy obstacles impede strong environmental policy. Institutional reforms provide one second-best alternative. Additionally, when international organizations like the International Monetary Fund, World Bank, regional development banks, and bilateral aid organizations advocate for improving institutions, this paper suggests that such reforms can also help improve their environment. I also find that such reforms reallocate dirty production to high income countries, however, which complicates the political economy of such reforms since high-income countries primarily fund the International Monetary Fund and World Bank.

I conclude with two open questions for future work. How do choices inside the firm mediate or magnify the effects of institutions on environmental quality? Firms respond to weak institutions in many ways, for example, by changing how transactions are financed (Antras and Foley 2015) or through vertical integration (Boehm and Oberfield 2020). Do firms in dirty and clean industries respond differently to the strength of a country's institutions? And how do such firm responses shape the intensity of pollution and international specialization in clean versus dirty production?

Second, how do institutions affect environmental quality through channels besides comparative advantage? Institutions may affect innovation, Coasian bargaining, and other channels. Just as research has found many channels for institutions to affect growth and economic activity, institutions may affect environmental quality through channels besides comparative advantage as well.

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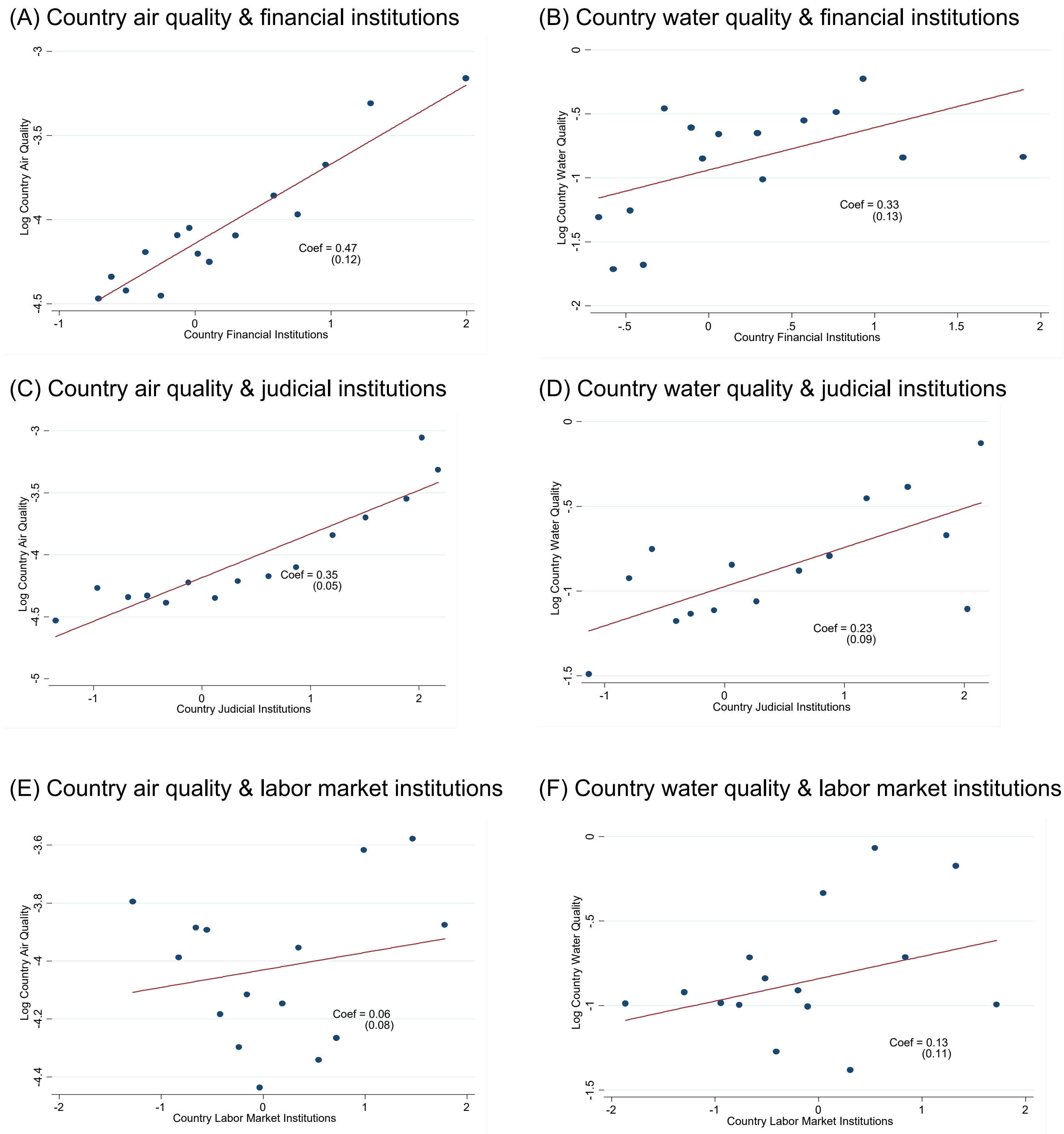
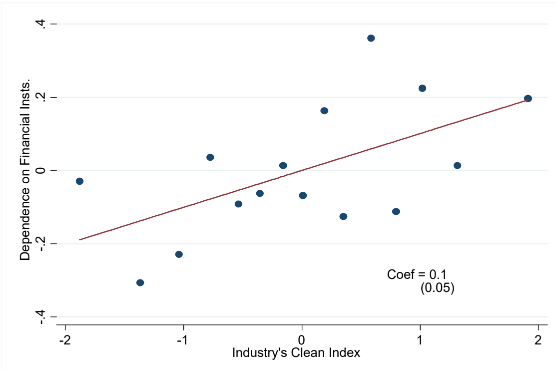
Figure 1. Country Environmental Quality and Country Institutions



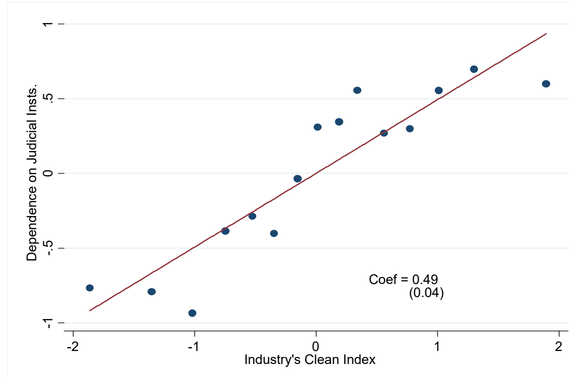
Notes: Each observation represents one country. Log of country environmental quality is negative one times the log of the country's mean $PM_{2.5}$ in μg/m^3 (Panels A, C, and E); or times the log of the country's mean biochemical oxygen demand in mg/L (Panels B, D, and F). Blue circles are means of 15 bins, each with equal number of countries. Red line is linear fit. "Coef" shows line slope and its robust standard error. Institutions are in z-scores.

Figure 2. Industry Dependence on Institutions and Industry Clean Index

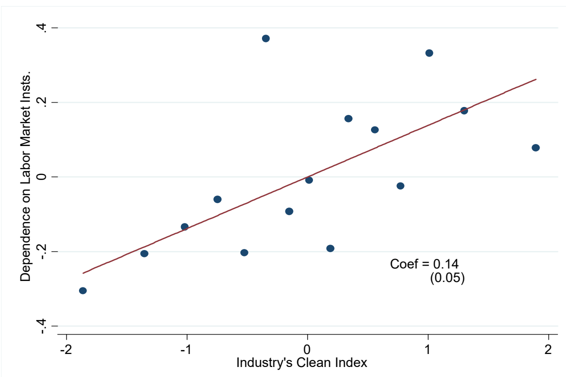
(A) Financial institutions



(B) Judicial institutions

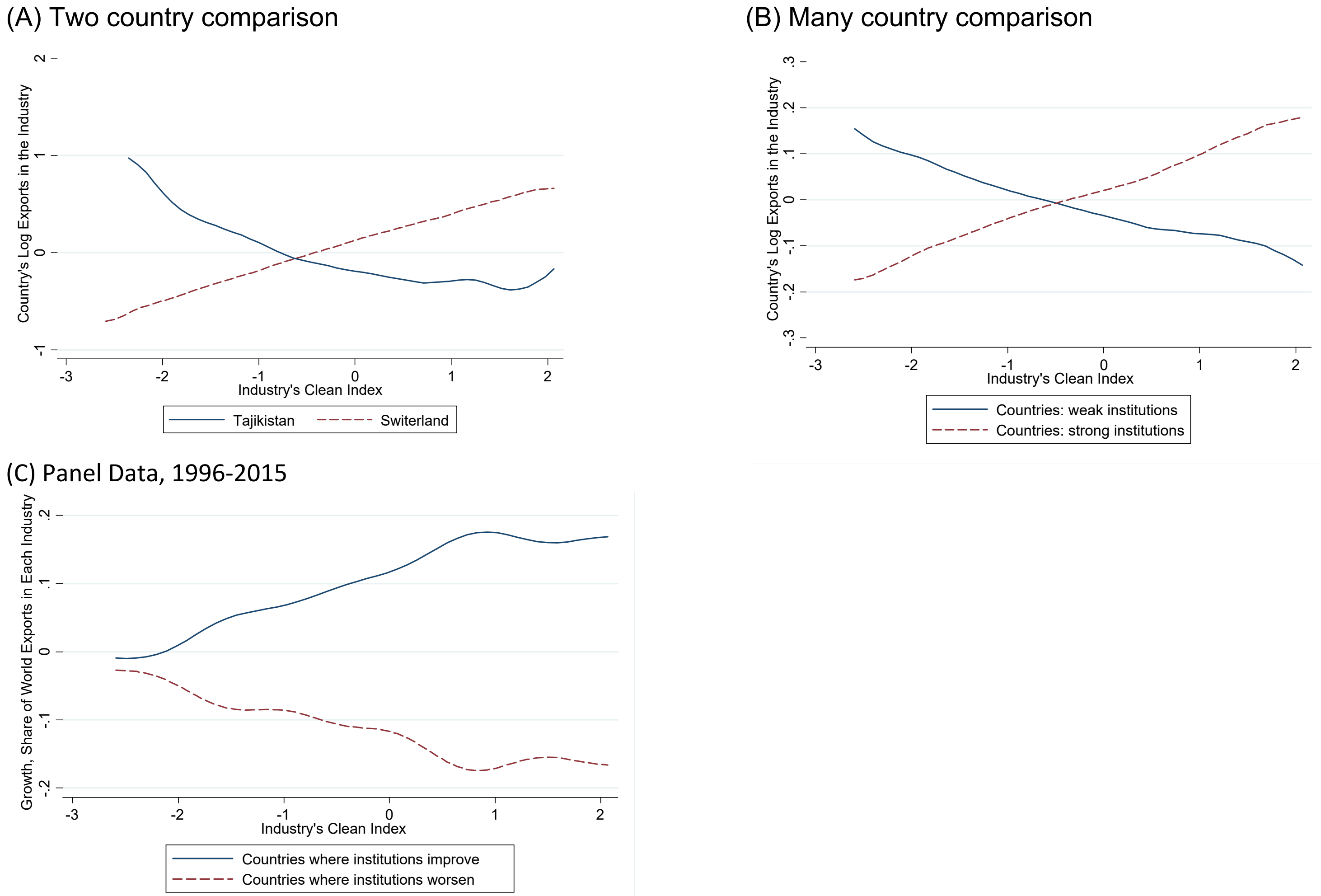


(C) Labor market institutions



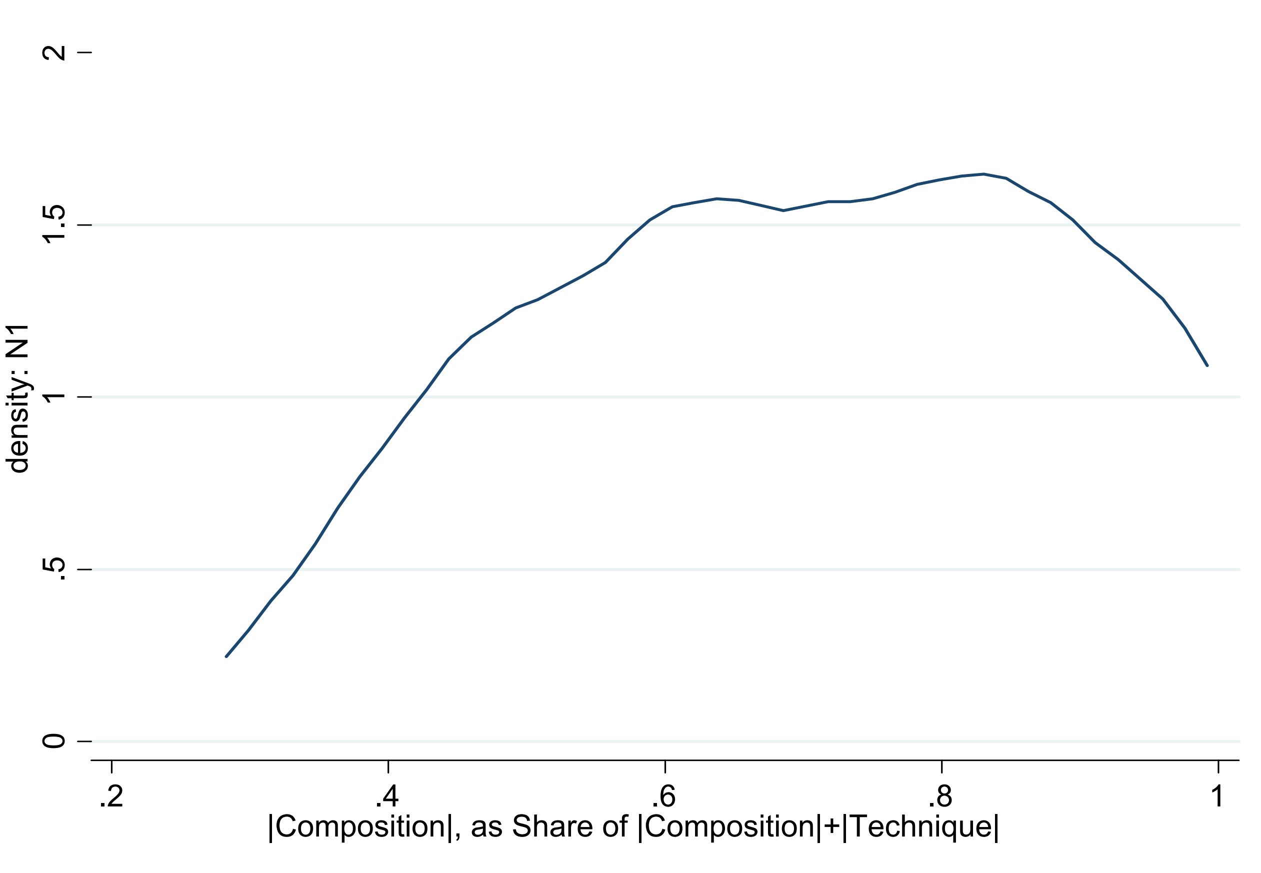
Notes: each observation is a manufacturing industry. Blue circles show means of 15 bins, each with an equal number of countries. Red line is linear fit. Dependence on institutions variables are in z-scores.

Figure 3. Industry Clean Index and Exports, by Strength of Country Institutions



Notes: in Panel A, Tajikistan has weak institutions while Switerland has strong institutions. In Panel B, "countries: weak institutions" includes all countries with below-median quality institutions, while "Countries: strong institutions" includes all countries with above-median quality institutions. Each graph shows two local linear regressions, with bandwidth of one, for manufacturing industries. For each line, the mean of log exports across industries is normalized to zero. Panel C divides countries into two groups: countries where national institutions improve between 1996 and 2015 and countries where institutions worsen. Institutions are measured by the principal component index of financial, judicial, and labor market institutions. This analysis calculates the share of world exports in each manufacturing industry that each of these two groups of countries represents in each year (1996 and 2015). Local linear regression is used to calculate nonparametrically smoothed export shares in each year, for each of the two groups of countries. The graph plots the change in that export share for each country group and industry between 1996 and 2015.

Figure 4. Importance of Composition Versus Technique, Distribution Across Countries



Notes: the graph plots the distribution across all possible reference countries and local pollutants. For each reference country *r*, the analysis calculates |*composition*| averaged across all country pairs while using *r* as reference, divided by |*composition*|+|*technique*| averaged across all countries while using *r* as reference. These values average across air pollutants in Exiobase. For example, the data point in this density with the US as reference country corresponds to |*composition*| / (|*composition*|+|*technique*|) from Table 6, column (1), rows 5-6. Calculations cover all industries. Pollution emission rates are winsorized at the 99.9th percentile.

Table 1—Industry Clean Index and Industry Dependence on Institutions

	Clean index	Industry dependence on institutions			
		Financial	Judicial	Labor markets	Index
	(1)	(2)	(3)	(4)	(5)
Panel A. Cleanest industries					
Office supply manufacturing	2.64	0.47	0.07	0.12	0.22
Instruments for industrial processes	2.58	1.75	1.18	-0.54	1.21
Fluid power pumps and motors	2.42	1.54	0.66	0.88	1.30
Curtain and linen mills	2.40	-0.23	0.54	1.35	0.90
Precision turned product manufacturing	2.23	-0.61	0.15	0.08	-0.03
Mean for cleanest industries	*2.46*	*0.58*	*0.52*	*0.38*	*0.72*
Panel B. Dirtiest industries					
Aluminum refining and production	-2.17	-0.49	-1.63	-0.53	-1.67
Gypsum product manufacturing	-2.18	-0.59	-1.16	-1.22	-1.60
Pulp mills	-2.22	-0.49	-0.48	-0.18	-0.61
Newsprint mills	-2.30	-0.53	-0.60	-0.81	-0.96
Other petroleum, coal products	-2.43	-0.22	-1.26	0.64	-0.84
Mean for dirtiest industries	*-2.26*	*-0.46*	*-1.03*	*-0.42*	*-1.14*

Notes: table includes manufacturing industries with non-missing values of all listed variables.

Table 2—Sources of Comparative Advantage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A. Comparative advantage in all industries										
Country endowment × industry intensity:										
Institutions: financ.	0.019***	—	—	—	—	—	—	—	0.011***	—
	(0.001)	—	—	—	—	—	—	—	(0.001)	—
Institutions: judicial	—	0.051***	—	—	—	—	—	—	0.035***	—
	—	(0.002)	—	—	—	—	—	—	(0.002)	—
Institutions: labor	—	—	0.003***	—	—	—	—	—	0.003***	—
	—	—	(0.001)	—	—	—	—	—	(0.001)	—
Institutions: index	—	—	—	0.052***	—	—	—	—	—	0.035***
	—	—	—	(0.002)	—	—	—	—	—	(0.002)
Environmental reg.	—	—	—	—	0.048***	—	—	—	0.026***	0.030***
	—	—	—	—	(0.002)	—	—	—	(0.002)	(0.002)
Factor capital/lab.	—	—	—	—	—	0.002	—	—	0.022***	0.020***
	—	—	—	—	—	(0.002)	—	—	(0.002)	(0.002)
Factor: skills	—	—	—	—	—	—	0.071***	—	0.056***	0.056***
	—	—	—	—	—	—	(0.002)	—	(0.002)	(0.002)
Tariffs	—	—	—	—	—	—	—	-0.049***	-0.049***	-0.049***
	—	—	—	—	—	—	—	(0.005)	(0.005)	(0.005)
N	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444
Panel B: Comparative advantage in clean industries										
Country endowment × clean industry index:										
Institutions: financ.	0.052***	—	—	—	—	–	–	–	0.035***	—
	(0.002)	—	—	—	—	–	–	–	(0.003)	—
Institutions: judicial	—	0.051***	—	—	—	–	–	–	0.010*	—
	—	(0.002)	—	—	—	–	–	–	(0.005)	—
Institutions: labor	—	—	0.019***	—	—	–	–	–	0.007***	—
	—	—	(0.002)	—	—	–	–	–	(0.002)	—
Institutions: index	—	—	—	0.054***	—	–	–	–	—	0.040***
	—	—	—	(0.002)	—	–	–	–	—	(0.003)
Environmental reg.	—	—	—	—	0.048***	–	–	–	0.009*	0.010***
	—	—	—	—	(0.002)	–	–	–	(0.005)	(0.003)
Country endowment × industry intensity:										
Factors capital/lab.	—	—	—	—	–	0.002	–	–	0.016***	0.016***
	—	—	—	—	–	(0.002)	–	–	(0.002)	(0.002)
Factors: skills	—	—	—	—	–	–	0.071***	–	0.060***	0.059***
	—	—	—	—	–	–	(0.002)	–	(0.002)	(0.002)
Tariffs	—	—	—	—	–	–	–	-0.049***	-0.049***	-0.049***
	—	—	—	—	–	–	–	(0.005)	(0.005)	(0.005)
N	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444
Fitted effect 10→90%	-21.2%	-34.0%	-15.4%	-35.4%	—	—	—	—	-23.6%	-26.7%
Importer×exporter FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Importer×industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Each observation is an importer×exporter×manufacturing industry. Dependent variable is log of bilateral trade. Table shows beta coefficients. In Panel A, the main explanatory variables are the interaction of an exporter's endowment with the industry's intensity. Fitted effect 10→90% implements equation (10). Columns (5) through (8) of Panel B repeat those of Panel A. Standard errors are clustered by importer×exporter pair. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Table 3—Institutions and Comparative Advantage, Alternative Research Designs

	All industries				Clean industries			
Institution:	Financial	Judicial	Labor	Inst. Index	Financial	Judicial	Labor	Inst. Index
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Baseline								
Institutions interaction	0.012***	0.036***	0.002***	0.035***	0.038***	0.034***	0.011***	0.040***
	(0.001)	(0.002)	(0.001)	(0.002)	(0.003)	(0.006)	(0.001)	(0.003)
Environmental regulation	0.040***	0.027***	0.040***	0.030***	0.017***	0.011**	0.038***	0.010***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.005)	(0.002)	(0.003)
N	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444
Panel B. Instrument with legal origins								
Institutions interaction	0.029***	0.059***	-0.004***	0.052***	0.034***	0.092***	0.026***	0.048***
	(0.002)	(0.005)	(0.001)	(0.004)	(0.012)	(0.013)	(0.003)	(0.005)
Environmental regulation	0.039***	0.018***	0.040***	0.025***	0.019**	-0.040***	0.036***	0.004
	(0.002)	(0.002)	(0.002)	(0.002)	(0.008)	(0.011)	(0.002)	(0.004)
N	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444
Panel C. Full panel								
Institutions interaction	0.002***	0.018***	0.003***	0.010***	0.005***	0.021***	0.006***	0.013***
	(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
N	29,615,619	31,205,815	29,179,570	27,743,169	30,409,354	31,205,815	29,179,570	28,488,568
Panel D. Long difference								
Institutions interaction	0.002	0.065***	0.034***	0.041***	0.014***	0.073***	0.050***	0.061***
	(0.003)	(0.014)	(0.009)	(0.008)	(0.004)	(0.014)	(0.008)	(0.008)
N	2,977,570	3,129,772	3,125,693	2,973,978	3,057,707	3,129,772	3,125,693	3,054,038
Panel E. Intra-national: India								
Institutions interaction	0.492***	0.096***	0.008	0.117***	0.837***	0.066***	-0.006	0.077***
	(0.104)	(0.020)	(0.017)	(0.010)	(0.091)	(0.017)	(0.015)	(0.009)
N	6,189	7,840	6,686	6,189	6,328	7,840	6,686	6,328
Importer×exporter FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Importer×industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Factor interactions, tariffs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: "Institution interaction" is interaction of county institutions×industry clean index. Environmental regulation is interaction of country environmental regulation and industry clean index. Additional controls in Panel E are state FE, industry FE, and factor interactions (no tariffs). Table entries show standardized beta coefficients, for manufacturing industries. Standard errors are clustered by importer×exporter pair. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Table 4: Which Industry Characteristics Explain the Importance of Institutions for Clean Industries?

	Association with clean index	Dependence of clean industries on institutions:			Comparative advantage of clean industries
		Financial	Judicial	Labor	
	(1)	(2)	(3)	(4)	(5)
Baseline	—	0.10**	0.49***	0.14***	0.054***
	—	(0.05)	(0.04)	(0.05)	(0.004)
Energy share	-0.37***	0.11*	0.42***	0.12***	0.053***
	(0.12)	(0.06)	(0.04)	(0.05)	(0.003)
Raw materials share	-0.36***	0.07	0.33***	0.15***	0.043***
	(0.05)	(0.06)	(0.04)	(0.05)	(0.003)
Upstreamness	-0.35***	0.09	0.37***	0.12**	0.059***
	(0.05)	(0.06)	(0.04)	(0.05)	(0.004)
Inverse export supply elasticity	0.27***	0.08	0.50***	0.12*	0.053***
	(0.06)	(0.07)	(0.05)	(0.06)	(0.004)
Mean wage	0.14**	0.08	0.45***	0.09*	0.053***
	(0.06)	(0.06)	(0.05)	(0.05)	(0.004)
Unemployment (%)	0.09*	0.13**	0.47***	0.11**	0.055***
	(0.05)	(0.06)	(0.05)	(0.05)	(0.004)
College educated	0.20***	0.05	0.45***	0.08	0.051***
	(0.06)	(0.06)	(0.05)	(0.05)	(0.004)
Union membership	-0.25***	0.14**	0.47***	0.10*	0.054***
	(0.05)	(0.07)	(0.05)	(0.06)	(0.004)
Intra-industry share	0.12*	0.09	0.56***	0.12**	0.055***
	(0.06)	(0.07)	(0.05)	(0.06)	(0.004)
Geographic dispersion	-0.02	0.12**	0.48***	0.10**	0.054***
	(0.06)	(0.06)	(0.05)	(0.05)	(0.004)
Labor share	0.27***	0.17***	0.43***	0.09	0.051***
	(0.05)	(0.06)	(0.05)	(0.06)	(0.004)
Capital share	-0.20***	0.10*	0.48***	0.10*	0.055***
	(0.07)	(0.06)	(0.05)	(0.05)	(0.004)
Log shipping cost per ton×km	-0.45***	0.00	0.41***	0.03	0.047***
	(0.06)	(0.09)	(0.06)	(0.07)	(0.004)
Mean firm size	-0.10***	0.13**	0.47***	0.10*	0.054***
	(0.04)	(0.06)	(0.05)	(0.05)	(0.004)
Std. dev. Firm size	-0.06	0.13**	0.48***	0.10*	0.054***
	(0.04)	(0.06)	(0.05)	(0.05)	(0.004)
Concentration ratio	-0.11*	0.13**	0.49***	0.10*	0.054***
	(0.06)	(0.06)	(0.05)	(0.05)	(0.004)
Log output	0.02	0.13**	0.47***	0.10*	0.054***
	(0.05)	(0.06)	(0.05)	(0.05)	(0.004)
Output trend 1977-2007	-0.11*	0.13**	0.48***	0.06	0.053***
	(0.06)	(0.06)	(0.05)	(0.05)	(0.004)
All at once	—	-0.08	0.13**	-0.02	0.033***
	—	(0.11)	(0.06)	(0.10)	(0.004)

Notes: Each table entry shows beta coefficients from a separate regression, limited to manufacturing. Column (1) regresses each variable on an indicator for whether the industry's clean index is above median. Columns (2)-(4) regress institutional dependence on the clean industry index and one additional variable shown in a given row; table entries show coefficient on the clean index. Column (5) estimates equation (4), but also controlling for the interaction of institutions with the variable indicated in each row. Parentheses show robust standard errors in columns (1)-(4) and standard errors clustered by country pair in column (5). Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Table 5—Effects of Counterfactual Institutions on Emissions: Model-Based Analysis

		Counterfactual change in…			Change: share output from…		
	Baseline institutions (z-score)	Institutional quality (z-score)	Emissions (%)	Emissions/ output (%)	Dirty industries	Moderate industries	Clean industries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Counterfactual: remove institutional differences between countries							
Pacific Ocean	1.9	-1.0	3.7%	5.5%	1.2%	0.2%	-1.4%
Western Europe	1.3	-0.4	0.7%	1.5%	0.3%	0.0%	-0.3%
Eastern Europe	0.2	0.6	-2.8%	-2.9%	-0.9%	-0.3%	1.2%
Latin America	-0.6	1.5	-11.0%	-11.5%	-1.3%	-0.8%	2.1%
North America	2.4	-1.6	2.9%	4.9%	0.7%	0.4%	-1.1%
China	0.7	0.2	-1.0%	-1.0%	-0.3%	-0.2%	0.5%
Southern Europe	0.7	0.1	-1.4%	-1.5%	-0.3%	-0.1%	0.4%
Northern Europe	2.2	-1.4	7.8%	9.6%	1.6%	0.7%	-2.3%
Indian Ocean	-0.3	1.2	-5.3%	-4.8%	-0.9%	-0.1%	1.0%
Rest of World	0.2	0.7	-6.1%	-6.0%	-1.0%	-0.6%	1.6%
Global	—	—	*-2.6%*	*-1.8%*	—	—	—
Panel B. Counterfactual: improve institutions in countries with below-median baseline institutions							
Pacific Ocean	1.9	0.0	3.7%	3.6%	0.8%	0.1%	-1.0%
Western Europe	1.3	0.0	3.5%	3.4%	0.7%	0.1%	-0.8%
Eastern Europe	0.2	1.5	-3.6%	-3.6%	-0.9%	-0.3%	1.2%
Latin America	-0.6	2.4	-13.1%	-13.6%	-1.4%	-0.7%	2.1%
North America	2.4	0.0	2.5%	2.3%	0.4%	0.2%	-0.5%
China	0.7	1.1	-2.9%	-2.5%	-0.6%	-0.1%	0.7%
Southern Europe	0.7	0.0	3.0%	2.8%	0.7%	0.1%	-0.8%
Northern Europe	2.2	0.0	3.9%	3.7%	0.6%	0.2%	-0.8%
Indian Ocean	-0.3	2.0	-6.6%	-5.6%	-0.8%	0.2%	0.6%
Rest of World	0.2	1.6	-7.5%	-7.1%	-1.0%	-0.2%	1.2%
Global	—	—	*-3.7%*	*-3.7%*	—	—	—
Panel C. Counterfactual: improve institutions in Latin America							
Pacific Ocean	1.9	0.0	0.4%	0.4%	0.1%	0.0%	-0.1%
Western Europe	1.3	0.0	0.4%	0.3%	0.1%	0.0%	-0.1%
Eastern Europe	0.2	0.0	0.2%	0.2%	0.1%	0.0%	-0.1%
Latin America	-0.6	3.1	-18.5%	-19.4%	-2.1%	-0.9%	3.0%
North America	2.4	0.0	1.0%	0.9%	0.1%	0.1%	-0.2%
China	0.7	0.0	0.3%	0.4%	0.1%	0.0%	-0.1%
Southern Europe	0.7	0.0	0.4%	0.3%	0.1%	0.0%	-0.1%
Northern Europe	2.2	0.0	0.5%	0.5%	0.1%	0.0%	-0.1%
Indian Ocean	-0.3	0.0	0.3%	0.3%	0.1%	0.0%	-0.1%
Rest of World	0.2	0.0	0.9%	0.9%	0.1%	0.0%	-0.2%
Global	—	—	*-0.9%*	*-1.0%*	—	—	—

Notes: institutional quality is principal component for each country. Dirty, moderate, and clean industries are based on dividing global industries into thirds based on global log emissions rate, measured as the first principal component of the log emissions rate across pollutants, and calculated as a weighted average across all countries. Data from Exiobase.

Table 6—Decomposition: Scale, Composition, and Technique, US as Reference

	All (1)	CO (2)	NO_x (3)	$PM_{2.5}$ (4)	SO_x (5)	VOCs (6)
1. Scale, composition, and technique	-0.72	-0.75	-0.83	-0.46	-0.68	-0.89
	(0.70)	(0.66)	(0.35)	(1.51)	(0.86)	(0.19)
2. Scale	-0.90	—	—	—	—	—
	(0.19)	—	—	—	—	—
3. Composition	1.75	1.22	2.09	2.79	2.09	0.57
	(1.21)	(1.20)	(1.45)	(1.97)	(2.21)	(0.55)
4. Technique	-0.03	0.09	-0.36	0.24	0.20	-0.32
	(0.59)	(0.75)	(0.43)	(1.07)	(1.18)	(0.31)
5. |Composition|	1.76	1.26	2.09	2.81	2.09	0.60
	(1.19)	(1.16)	(1.44)	(1.94)	(2.21)	(0.52)
6. |Technique|	0.47	0.51	0.49	0.73	0.86	0.38
	(0.36)	(0.56)	(0.28)	(0.81)	(0.82)	(0.22)

Notes: calculations use full Exiobase data. Scale, composition, and technique are all proportional difference relative to US. Row 2 uses production but not pollution data, so it is identical across pollutants. Emission rates are winsorized at 99.9th percentile. Calculations cover all industries.

Online Appendix

Institutions, Comparative Advantage, and the Environment

Joseph S. Shapiro

Table of Contents

A Data Details

A.1 General Data Details

CEPII reports import tariffs in the year 2010 for all but three countries that have data on other required variables (institutions, etc.). For Thailand, I use year 2007 rather than 2010 tariff data. For Iraq and Liberia, I average tariffs within industry code for the adjacent countries (for Iraq, I average Iran, Kuwait, Saudi Arabia, Jordan, Syria, and Turkey; for Liberia, I average Sierra Leone, Guinea, and Code d'Ivoire). One estimate uses measures of bilateral trade frictions (distance, common language, etc.) from CEPII's Gravity database.

I report sensitivity analyses examining 12 alternative measures of institutions. One sensitivity analysis defines financial institutions according to measures of financial institution and market development from the International Monetary Fund (Svirydzenka 2016*a*). Another analysis defines the quality of a country's financial institutions according to the measure of this concept reported in the World Bank's Doing Business Report (World Bank 2007).

For estimates using Exiobase, Shapiro (2021) describes details of cleaning and setting up these data. The air pollution measures in Exiobase use observed information from North America, Europe, and Asia where available, and complete additional pollution measures use information on production technologies by sector and aggregate emissions (Stadler et al. 2018). Exiobase records non-methane volatile organic compounds, which is similar but not identical to the total volatile organic compounds that the National Emissions Inventory reports. Methane is sometimes separated as an organic compound since it is less reactive to form ambient ozone pollution (Jacobsen et al. 2023).

For judicial institutions, sensitivity analyses consider the Fraser Institute (2021)'s index of legal and property rights and the World Bank (2007)'s Doing Business index of contract enforcement.

For labor market institutions, I report sensitivity analyses that use the employment protection index from the International Labor Organization (2015), the employing workers index from the World Bank (2007)'s Doing Business Report, the index of labor market efficiency from the World Economic Forum (2015), and Botero et al. (2004)'s index of employment laws. I multiply the International Labor Organization, World Bank, and Botero et al. indices, which are designed to measure labor market restrictiveness, by negative one so that more positive values of the labor market institutions index represent more flexible labor market institutions.

In the sensitivity analysis using panel data, because labor institutions data are only available for the period 2005-2016, I assume labor institutions are constant over the period 1996-2005. Data on judicial institutions are missing in years 1997, 1999, and 2001, so for the sensitivity analysis using panel data, I linearly interpolate values for these years only within each country.

The National Emissions Inventory (NEI) provides the most accurate industry-level emissions data of which I am aware, in any country. The NEI is collected every three years, so I use data from the 2011 edition, which is the closest to year 2012. Some firms report pollution with a 6-digit NAICS code, while others report a more aggregate industry code. I measure pollution for each 6-digit NAICS code in the analysis using the most detailed industry code available from the NEI.

A subset of NEI plants have continuous emissions monitoring devices. NEI only federally mandates reporting for plants where the estimated maximum possible pollution emissions (the "potential to emit") exceeds a threshold. This requirement could raise concerns about size-based sample selection into the NEI. In practice, many plants are required to report data well below the federal threshold. Additionally, plants mandated to report under any one of NEI's several hundred pollutants typically report emissions for many pollutants, not only the required pollutant. For example, for some pollutants the federal reporting standard is that a plant must have "potential to emit" above 100 tons per year, but 97 percent of facility×pollutant criteria pollution reports in the 2011 NEI have emissions below this threshold, and median plant-level emissions in the NEI for each criteria pollutant are well below one ton.

For the industry characteristics data used in Table 4 that help explain why clean industries depend on institutions, many records are adapted from Shapiro (2021) and represent the year 2007.

Large polluting plants must report quarterly concentrations or quantities of many regulated water pollutants to the EPA. The discharge microdata have numerous outflows and measures of concentration per establishment, so I use aggregate emissions data from the EPA's online discharge reporting tool.

To study intra-national production in India, I use production decisions from India's 2015-2016 Annual Survey of Industries. The survey includes all registered factories with over 100 workers and a sample of smaller establishments.

A.2 Institutions

This subsection provides additional detail on the measures of national institutions. The index of financial institutions measures the depth of bank, finance, and insurance markets, access to bank branches and ATMs, and efficiency in intermediating savings to investment, operational efficiency, and profitability of financial institutions (Svirydzenka 2016*b*). The World Bank index of judicial institutions is constructed from international polls, global surveys, and country ratings by many international organizations and risk-rating agencies.

To define each industry's dependence on judicial institutions, I use data on whether each good is sold on an open exchange, reference-priced, or has decentralized exchange; and input shares data from the 2012 Bureau of Economic Analysis Use table, at detail after redefinitions. Rauch reports four measures (liberal and conservative measures of the share of goods that are differentiated or not priced on open markets). My main results use Rauch's liberal definition of the share of goods that are differentiated (i.e., not referenced priced or traded on open markets), since it has the most variability across industries.

Despite their wide use in trade research, one could have several concerns about this paper's measures of an industry's dependence on institutions. These proxies might not perfectly measure the true dependence of an industry on an institution. Additionally, measuring these variables in US data describes a country with strong institutions; the importance of institutions for each industry could vary by country. Similarly, an industry in the US could depend on an institution (e.g., judicial institutions) due to an omitted variable which differs across industries, e.g., the network structure of the US economy which makes some industries use relatively complex inputs.

While the aforementioned concerns are relevant, this paper's key regressions which interact an industry's clean index with a country's institutions do not depend on these measures of each industry's dependence on institutions, although the pairwise correlations of an industry's clean index with the industry's dependence on institutions do depend on these measures. Additionally, if the measures of each industry's dependence on institutions do not extrapolate well to other countries, or poorly measure true dependence on institutions for the US, those errors in variables would tend to attenuate estimates of relationships between these variables and outcomes, and could suggest that true effects of institutions are even larger than this paper estimates. The aforementioned reasons for using US data (industry detail, measurement quality etc.) also apply here.

A.3 Concordance Files

I use several concordance files to ensure all data have the same country and industry classifications. I obtain raw bilateral trade data from CEPII-BACI, at the 6-digit Harmonized System (HS) code level. I concord this to the US NAICS industry code level using links between these industry codes from the US Census Bureau's Imports and Exports of Merchandise data.

The classification of industries as traded on open markets, reference-priced, or differentiated uses the SITC industry classification (Rauch 1999). I link these to Harmonized System (HS) codes using a concordance file from the United Nations, and then translate from HS to NAICS using the aforementioned concordance.

I translate various data to U.S. industry codes using other standard concordance files. Some of the industry characteristics are reported in North American Industry Classification System (NAICS) codes from other years like 2002 or 2007, and I use US industry concordances to translate these to the 2012 NAICS codes used in the rest of the paper. For data reported using SIC industry codes, I translate these to NAICS using a concordance file derived from Fort and Klimek (2016). Other industry characteristics are derived from the U.S. input-output table, and I translate input-output industry codes to NAICS industry codes using a concordance file from the Bureau of Economic Analysis.

B Alternative Specifications for Comparative Advantage

Appendix Table 6 shows results from alternative approaches to estimate how institutions affect comparative advantage in clean industries. Appendix A.1 describes data used in several of these estimates. Row 1 re-states the main results from Table 2. Row 2 includes all three institutions simultaneously. Row 3 includes all industries, not only manufacturing. Row 4 replaces the bilateral fixed effects from equation (9) with exporter fixed effects η_i^C and controls for bilateral trade frictions from CEPII—bilateral distance, common language, colonizer, religion, legal origin, regional trade agreement, and World Trade Organization membership. Row 5 uses Exiobase, at the same level of observation as the quantitative model. Row 6 estimates the regression in levels, including zero trade flow observations, using Poisson pseudo maximum likelihood (Silva and Tenreyro 2006). Row 7 measures pollution from the Leontief Inverse Matrix of the Input-Output table, which includes emissions embodied in the entire value chain of a good. Row 8 replaces the clean industry index with an indicator for the cleanest roughly 90 percent of industries, which makes this estimate focus on extensive margin differences between especially dirty industries and others, a binary distinction which is commonly analyzed in the Pollution Havens Hypothesis literature. Row 9 regresses the clean index on industry fixed effects and a country's institutions index, as one way to learn about how institutions relate to cross-country and within industry differences in production techniques, as in equation (13).

These sensitivity analyses in Appendix Table 6 obtain results that are qualitatively similar to the main estimates, though magnitudes vary across samples and specifications. For example, nearly all the alternative estimates are positive and most are statistically distinguishable from zero. Financial and judicial institutions appear to drive trade more than labor market institutions. Adjusting estimates with methods to account for zero trade flows somewhat decreases the importance of institutions overall but increases their importance for clean industries.

C Details of Scale, Composition, and Technique Decomposition

Many papers report the following decomposition, where x_{rs} represents gross output in industry s and reference (baseline) year r, e_{rs} represents the emission rate from in the reference year, κ_{is} is the share of the economy's gross output from industry s in year i, and X_i is the economy's gross output in year i:

$$\text{Scale} = \frac{X_i}{X_r} \tag{C–1}$$

$$\text{Scale+Composition} = \frac{X_i \sum_s \kappa_{is} e_{rs}}{X_r \sum_s \kappa_{rs} e_{rs}} = \frac{X_i \sum_s \kappa_{is} e_{rs}}{\mathcal{E}_r} \tag{C–2}$$

$$\text{Scale+Composition+Technique} = \frac{X_i \sum_s \kappa_{is} e_{is}}{X_r \sum_s \kappa_{rs} e_{rs}} = \frac{\mathcal{E}_i}{\mathcal{E}_r} \tag{C–3}$$

The second and third lines use the fact that an economy's total emissions in a year are $\mathcal{E}_i = X_i \sum_s \kappa_{is} e_{is}$.

These equations have simple interpretations. The scale effect (C–1) equals the ratio of gross output in year i relative to the baseline year r. This is identical to the Scale effect from the main text, in equation (21). Scale+Composition (C–2) allows gross output X and output shares κ to evolve following actual data in year i, but holds emission rates fixed in the baseline year r. Specifically, Scale+Composition evaluates pollution in year i as gross output in that year, multiplied by the sum of output shares in that year, but evaluated at baseline emission rates. The third equation (C–3), Scale+Composition+Technique, equals the ratio of national pollution emissions in year i relative to the baseline year r.

How do these equations relate to the Composition and Technique equations from the main text? The composition effect from the main text, in equation (22), equals Scale+Composition in equation

(C–2) divided by Scale in equation (C–1):

$$\text{Composition} = \frac{\sum_s \kappa_{is} e_{rs}}{\sum_s \kappa_{rs} e_{rs}} = \frac{\frac{X_i \sum_s \kappa_{is} e_{rs}}{X_r \sum_s \kappa_{rs} e_{rs}}}{\frac{X_i}{X_r}}$$

The technique effect from the main text, in equation (23), equals Scale+Composition+Technique from equation (C–3), divided by Scale+Composition from equation (C–2):

$$\text{Technique} = \frac{\sum_s \kappa_{is} e_{is}}{\sum_s \kappa_{is} e_{rs}} = \frac{\frac{X_i \sum_s \kappa_{is} e_{is}}{X_r \sum_s \kappa_{rs} e_{rs}}}{\frac{X_i \sum_s \kappa_{is} e_{rs}}{X_r \sum_s \kappa_{rs} e_{rs}}}$$

D Quantitative Model of Trade, Institutions, and Pollution

This appendix section describes the quantitative model. The representative agent in country j maximizes utility U_j, which is a CES aggregate across varieties and a Cobb-Douglas aggregate across sectors:

$$U_j = \prod_s \left[\left(\int_\Omega q_{j,s}(\omega)^{\frac{\sigma_s - 1}{\sigma_s}} d\omega \right)^{\frac{\sigma_s}{\sigma_s - 1}} \right]^{\beta_{j,s}} f(\mathcal{E}_j)$$

Here $q_{js}(\omega)$ is the quantity of variety ω shipped from origin i to destination j in sector s, σ is the elasticity of substitution across varieties, and β_{js} is the Cobb-Douglas expenditure share. The representative agent experiences disutility $f(\cdot)$ from pollution $\mathcal{E}_j$, which I treat as a pure externality that does not directly affect expenditure decisions.

Trade. For each variety, producers in a country draw a productivity from a Fréchet distribution with location parameter $T_{i,s}$ and dispersion parameter θ_s. Buyers source each variety from the seller with the lowest offered price. The associated price index is

$$P_{j,s} = \xi_1 \left[\sum_i T_{i,s} (c_{i,s} \phi_{ij,s})^{-\theta_s} \right]^{-1/\theta_s}$$

where the trade elasticity is $\theta_s = \sigma_s - 1$ and ξ_1 is a constant function of θ_s and σ_s. Goods face iceberg trade costs $\tau_{ij,s} \geq 1$ where τ goods must be shipped for one to arrive, and tariffs $t_{ij,s}$. The full trade cost is $\phi_{ij,s} \equiv \tau_{ij,s}(1 + t_{ijs})$. Although counterfactual policies do not change tariffs, given the differences in trade policy between clean and dirty industries (Shapiro 2021), the model accounts for pre-existing tariff levels.

Production. Production is Cobb-Douglas and uses labor, hired at wage w_i, and intermediate goods, with cost share $\alpha_{ik,s}$ for sector k inputs used to produce sector s outputs. The unit cost function is

$$c_{i,s} = \xi_2 w_i^{1-\alpha_{i,s}} \prod_k P_{i,k}^{\alpha_{i,ks}}$$

where ξ_2 is a constant function of model parameters.

Pollution. The pollution emitted in country i is

$$\mathcal{E}_i = \sum_s \frac{\gamma_{i,s} R_{i,s}}{c_{i,s}}$$

where $\gamma_{i,s}$ measures the baseline units of pollution emitted per real output. This assumes that within a country and industry, pollution is a fixed feature of production that is invariant to counterfactual reforms. Such an assumption would not be appropriate for counterfactual changes like reforming environmental policy. It is a plausible simplification for an analysis of how broad changes in institutions affect comparative advantage and reflects discussion and analysis from the main text of institutions limited impact on production techniques. While reforms for energy and fossil fuels would change prices and supply of these energy goods, air and water pollution are not traded in such global markets, so these concerns are less important for pollution. Finally, institutions could change an industry's pollution intensity $\gamma_{i,s}$ through changing inputs or technology. This analysis provides a conservative role for institutions, by shutting this channel off. Because institutions in this model affect pollution through comparative advantage, if all countries improve institutions proportionally, global pollution does not change.

Equilibrium. I study a competitive equilibrium, in which consumers maximize utility, firms maximize profits, and markets clear. Total country×sector expenditure, $X_{j,s}$, equals the sum of expenditure on final and intermediate goods:

$$X_{j,s} = \beta_{j,s}(Y_j + D_j + G_j) + \sum_k \alpha_{j,sk} R_{j,k}$$

where fixed deficits are given by D_j, government tariff revenues by G_j, and country×sector revenues by $R_{i,s} = \sum_j X_{ij,s}$.

To study effects of counterfactuals, I express variables in changes (Dekle, Eaton and Kortum 2008). For any variable a in the model, let a' denote the value in a counterfactual and let $\hat{a} = a'/a$ denote the proportional change due to a counterfactual. I let global GDP serve as the numeraire. The change in expenditure shares due to a counterfactual is

$$\hat{\lambda}_{ij,s} = \hat{T}_{i,s} \left(\frac{\hat{c}_{i,s} \hat{\phi}_{ij,s}}{\hat{P}_{j,s}} \right)^{-\theta_s} \tag{D–4}$$

where $\lambda_{ij,s} \equiv X_{ij,s} / \sum_i X_{ij,s}$ is the share of (j,s) expenditure on goods from exporting country i. The change in cost shares, country×sector price index, expenditure, and revenues, are

$$\hat{c}_{i,s} = \hat{w}_i^{1-\alpha_{i,s}} \prod_k \hat{P}_{i,k}^{\alpha_{i,ks}} \tag{D–5}$$

$$\hat{P}_{j,s} = \left[\sum_i \lambda_{ij,s} \hat{T}_{i,s} (\hat{c}_{i,s} \hat{\phi}_{ij,s})^{-\theta_s} \right]^{-1/\theta_s}$$

$$\hat{X}_{j,s} X_{j,s} = \frac{\beta_{j,s}}{1 - \sum_{i,s} \frac{t_{ij,s}}{1+t_{ij,s}} \hat{\lambda}_{ij,s} \lambda_{ij,s} \beta_{j,s}} (\hat{w}_j Y_j + D_j + \sum_{i,l} \frac{t_{ij,l}}{1+t_{ij,l}} \hat{\lambda}_{ij,l} \lambda_{ij,l} \sum_k \alpha_{j,lk} \hat{R}_{j,k} R_{j,k}) + \sum_k \alpha_{j,sk} \hat{R}_{j,k} R_{j,k}$$

$$\hat{R}_{i,s} = \frac{\sum_j X'_{ij,s}}{\sum_j X_{ij,s}} \tag{D–6}$$

Counterfactual revenues equal $\hat{R}_{i,s} R_{i,s} = \hat{w}_i \hat{y}_{i,s} y_{i,s} Y_i / (1 - \alpha_{i,s})$. Bilateral sales are given by $X'_{ij,s} = \hat{\lambda}_{ij,s} \lambda_{ij,s} \hat{X}_{j,s} X_{j,s}$, and counterfactual industry shares are given by

$$\sum_s \hat{y}_{i,s} y_{i,s} = 1 \tag{D–7}$$

E Appendix Figures and Tables

Appendix Table 1: Data Sources and Variables

Variable	**Measure**	**Source, Notes**
Panel A. Country level variables		
Institutions: financial	Private credit by deposit and money institutions / GDP	World Bank Financial Structure Database
Institutions: judicial	Rule of law index	Kauffman et al. (2011)
Institutions: labor	Labor market freedom index	Heritage Foundation (2021)
Environmental regulation	Sulfur standard for diesel; enviro. regulation enforcement; enviro. regulation stringency; enviro. treaties signed; air quality standards for particulates, sulfur dioxide; lead standard for gasoline; enviro. taxes / GDP.	World Economic Forum (2013); IMF (2022): Joss et al. (2017); Broner et al. (2011); UNEP (2022)
Factor endowments	Log capital stock per worker; human capital index	Penn World Tables (Feenstra et al. 2021)
Ambient pollution	Particulate matter smaller than 10 micrometers (PM_{10}) and biochemical oxygen demand (BOD)	Global Environmental Monitoring System for freshwater (GEMStat)
Panel B. Industry level variables		
Institution intensity: financial	Share of capital expenditures not funded by internal cash flow	Compustat North America. From Rajan and Zingales (1998)
Institution intensity: judicial	Share of industry's inputs not traded on open markets or reference priced	BEA input-output table, Rauch (1999). From Nunn (2007)
Institution intensity: labor	Standard deviation of within-firm sales growth	Compustat North America. From Cunat and Melitz (2012)
Air pollution emissions	Carbon monoxide, nitrogen oxides, particulate matter smaller than 2.5 micrometers, sulfur dioxide, and volatile organic compounds, log pollution per dollar revenue	Year 2011 National Emissions Inventory from US Environmental Protection Agency
Water pollution emissions	Total pounds, log per dollar revenue	US Dicharge Monitoring Reports
Revenues	Industry total value of shipments	US Census of Manufactures
Panel C. Country pair×industry and other data		
Trade, pollution		Exiobase
Trade		CEPII *Base pour Analyse du Commerce International* (BACI)
Tariffs	Applied tariffs	CEPII Market Access Map (Macmap)
Production		India's Annual Survey of Industry

Appendix Table 2—Correlation Between Country Characteristics and Between Industry Characteristics

	Institutions				Factor		Enviro. reg.,
	Financial	Judicial	Labor	Index	Capital	Skills	clean index
	(1)	(2)	(3)	(4)	(5)	(6)	(9)
Panel A. Country characteristics							
Institutions: financial	1.00	—	—	—	—	—	—
Institutions: judicial	0.76	1.00	—	—	—	—	—
Institutions: labor	0.17	0.26	1.00	—	—	—	—
Institutions: index	0.82	0.91	0.58	1.00	—	—	—
Factor intensity: capital	0.65	0.72	0.16	0.68	1.00	—	—
Factor intensity: skills	0.59	0.66	0.14	0.62	0.78	1.00	—
Enviro. regulation	0.74	0.88	0.13	0.79	0.68	0.65	1.00
Panel B. Industry characteristics							
Institutions: financial	1.00	—	—	—	—	—	—
Institutions: judicial	0.16	1.00	—	—	—	—	—
Institutions: labor	0.22	-0.01	1.00	—	—	—	—
Institutions: index	0.49	0.85	0.45	1.00	—	—	—
Factor intensity: capital	-0.02	-0.44	-0.14	-0.42	1.00	—	—
Factor intensity: skills	0.25	0.28	0.07	0.32	0.02	1.00	—
Clean index	0.10	0.50	0.14	0.49	-0.48	0.32	1.00

Notes: table entries show correlation coefficients between the variables. In Panel A, each observation is a country, table uses countries where all these variables are non-missing, N=120. In Panel B, each observation is an industry, N=364.

Appendix Table 3—Institutions and Legal Origin Interactions: First-Stage Estimates

	All industries				Clean industries			
Which institutions:	Financial	Judicial	Labor	Inst. Index	Financial	Judicial	Labor	Inst. Index
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Clean index × …								
Legal origins: British	-0.012***	0.005	0.053***	0.084***	-0.123***	0.011	0.652***	0.186***
	(0.004)	(0.006)	(0.003)	(0.013)	(0.040)	(0.014)	(0.046)	(0.027)
Legal origins: French	-0.020***	-0.088***	-0.017***	-0.096***	-0.255***	-0.158***	-0.105*	-0.181***
	(0.005)	(0.008)	(0.004)	(0.014)	(0.049)	(0.015)	(0.057)	(0.029)
Legal origins: German	-0.028***	-0.076***	0.001	-0.070***	-0.200***	-0.130***	0.023	-0.118***
	(0.004)	(0.005)	(0.003)	(0.012)	(0.037)	(0.011)	(0.045)	(0.023)
Legal origins: Socialist	-0.016***	-0.029***	0.004*	-0.029***	-0.133***	-0.051***	0.066**	-0.051**
	(0.003)	(0.003)	(0.002)	(0.010)	(0.026)	(0.006)	(0.033)	(0.020)
N	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444	1,826,444
R-K F Statistic	16.5	97.5	269.4	213.9	10.8	65.8	242.7	164.4
Importer×exporter FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Importer×industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Factor interactions, tariffs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: Each table entry shows beta coefficients. Standard errors are clustered by importer×exporter pair. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 4—Comparative Advantage: Other Measures of Regulation

Industries:	All (1)	Clean (2)
1. Institutions index	0.035***	0.034***
	(0.002)	(0.002)
Environmental regulation mean percentile	0.107***	0.066***
	(0.005)	(0.007)
N	1,826,444	1,826,444
2. Institutions index	0.036***	0.035***
	(0.002)	(0.002)
Environmental regulation mean z score	0.034***	0.021***
	(0.002)	(0.002)
N	1,826,444	1,826,444
3. Institutions index	0.037***	0.059***
	(0.002)	(0.003)
Environmental enforcement	0.017***	-0.014***
	(0.002)	(0.003)
N	1,826,444	1,826,444
4. Institutions index	0.037***	0.048***
	(0.002)	(0.003)
Environmental stringency	0.023***	-0.001
	(0.002)	(0.003)
N	1,826,444	1,826,444
5. Institutions index	0.042***	0.046***
	(0.002)	(0.002)
Environmental treaties	0.012***	0.008***
	(0.002)	(0.002)
N	1,826,444	1,826,444
6. Institutions index	0.039***	0.045***
	(0.002)	(0.002)
Air quality std. for particulates	0.008***	0.003
	(0.002)	(0.002)
N	1,624,612	1,624,612
7. Institutions index	0.038***	0.043***
	(0.002)	(0.002)
Air quality std. for sulfur dioxide	0.008***	0.003**
	(0.002)	(0.002)
N	1,574,376	1,574,376
8. Institutions index	0.034***	0.032***
	(0.002)	(0.002)
Gasoline standard for lead	0.043***	0.033***
	(0.002)	(0.003)
N	1,560,732	1,560,732

9. Institutions index	0.037***	0.035***
	(0.002)	(0.002)
Diesel standard for sulfur	0.042***	0.032***
	(0.002)	(0.003)
N	1,826,444	1,826,444
10. Institutions index	0.039***	0.041***
	(0.002)	(0.002)
Environmental taxes / GDP	0.005***	0.005***
	(0.002)	(0.002)
N	1,584,110	1,584,110

Notes: Column (1) shows the coefficients on country institution endowment×industry institution intensity and on country environmental regulation×industry clean index. Column (2) shows the coefficient on country institution endowment×industry clean index. Each table entry shows beta coefficients from a separate regression. Row 1 constructs the first principal component of the eight separate measures of regulation. All regressions control for importer×exporter FE, importer×industry FE, factor endowments×factor intensity, environmental regulation×pollution intensity, and tariffs. Standard errors are clustered by importer×exporter pair. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 5—Comparative Advantage: Other Measures of Institutions

Industries:	All (1)	Clean (2)
Country financial institutions interactions		
1. IMF financial development	0.029***	0.066***
	(0.001)	(0.003)
N	1,820,639	1,820,639
2. IMF financial markets	0.024***	0.054***
	(0.001)	(0.003)
N	1,820,639	1,820,639
3. World Bank credit institutions	0.035***	0.061***
	(0.003)	(0.007)
N	1,826,444	1,826,444
Country judicial institutions interactions		
4. Fraser Institute judicial institutions	0.151***	0.097***
	(0.008)	(0.020)
N	1,826,444	1,826,444
5. World Bank number of procedures	0.081***	0.024**
	(0.010)	(0.010)
N	1,826,444	1,826,444
6. World Bank number of days	0.019***	-0.003
	(0.004)	(0.004)
N	1,826,444	1,826,444
7. World Bank percent cost	0.008***	0.005**
	(0.002)	(0.002)
N	1,826,444	1,826,444
Country labor market institutions interactions		
8. ILO labor protection	0.014***	0.007
	(0.003)	(0.006)
N	1,609,287	1,609,287
9. Doing Business Report--rigidity	0.002	0.025***
	(0.001)	(0.003)
N	1,826,444	1,826,444
10. World Economic Forum efficiency	0.022***	0.088***
	(0.005)	(0.013)
N	1,823,957	1,823,957
11. Botero et al. (2004)	0.007***	0.053***
employment laws	(0.003)	(0.004)
N	1,635,297	1,635,297

12. Botero et al. (2004)	0.011***	0.014**
collective relations laws	(0.003)	(0.006)
N	1,635,297	1,635,297
Constraint on executive versus credit market institutions		
13. Constraint on the executive	0.091***	0.031***
	(0.010)	(0.011)
N	1,818,583	1,818,583
14. Constraint on the executive:	0.167***	0.122***
settler mortality IV	(0.032)	(0.035)
N	794,086	794,086
15. Constraint on the executive:	0.589***	1.637
1500 pop. Density IV	(0.108)	(1.008)
N	1,748,835	1,748,835
16. Contracting institutions	0.010***	0.006***
	(0.002)	(0.002)
N	1,719,467	1,719,467
17. Contracting institutions:	0.022***	0.030***
Legal origins IV	(0.003)	(0.003)
N	1,719,467	1,719,467
18. Both:		
Constraint on the executive	0.080***	0.018
	(0.011)	(0.013)
Contracting institutions	0.012***	0.007***
	(0.002)	(0.002)
N	1,712,983	1,712,983
19. Both: settler mortality and legal origins IV		
Constraint on the executive	-0.402***	-0.061
	(0.105)	(0.041)
Contracting institutions	0.122***	0.070***
	(0.020)	(0.007)
N	763,144	763,144
20. Both: 1500 pop. density and legal origins IV		
Constraint on the executive	0.831***	12.245
	(0.190)	(34.622)
Contracting institutions	0.063***	0.429
	(0.011)	(1.020)
N	1,664,812	1,664,812
21. Both: 1500 pop density, settler mortality, and legal origins IV		
Constraint on the executive	0.013	-0.030
	(0.028)	(0.026)
Contracting institutions	0.055***	0.065***

	(1)	(2)
	(0.005)	(0.005)
N	763,144	763,144

Notes: Column (1) shows the coefficient on country institution endowment×industry institution intensity. Column (2) shows the coefficient on country institution endowment×industry clean index. Each table entry shows beta coefficients from a separate regression. All regressions control for importer×exporter FE, importer×industry FE, factor endowments×factor intensity, environmental regulation×pollution intensity, and tariffs. Standard errors are clustered by importer×exporter pair. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 6—Other Sensitivity Analyses for Institutions and Comparative Advantage

Industries:	All	Clean
	(1)	(2)
1. Baseline estimates	0.035***	0.040***
	(0.002)	(0.003)
N	1,826,444	1,826,444
2. All institution interactions at once		
Financial institutions	0.011***	0.035***
	(0.001)	(0.003)
Judicial institutions	0.035***	0.010*
	(0.002)	(0.005)
Labor market institutions	0.003***	0.007***
	(0.001)	(0.002)
N	1,826,444	1,826,444
3. All industries, not just manufacturing	0.036***	0.044***
	(0.002)	(0.003)
N	1,866,538	1,932,690
4. Trade frictions, not i,j FE	0.035***	0.041***
	(0.002)	(0.003)
N	1,725,382	1,725,382
5. Exiobase	0.018***	0.052***
	(0.006)	(0.008)
N	87,200	88,843
6. Poisson pseudo maximum likelihood	0.123***	0.057***
	(0.007)	(0.007)
N	3,954,353	4,072,672
7. Leontief Inverse matrix	—	0.035***
	—	(0.002)
N	—	1,811,952
8. Indicator for dirtiest industries	—	0.040***
	—	(0.003)
N	—	1,826,444
9. Institutions and technique	-0.018	—
	(0.037)	—
N	6,303	—

Notes: In rows 1-8, column (1) shows the coefficient on country institution endowment×industry institution intensity. Column (2) shows the coefficient on country institution endowment×industry clean index. Each table entry shows beta coefficients from a separate regression. Regressions control for importer×exporter FE, importer×industry FE, factor endowments×factor intensity, environmental regulation×pollution intensity, and tariffs. Row 3 assumes non-manufacturing industries have mean capital and labor levels. Row 9 regresses country×industry clean index from Exiobase on country institutions, environmental regulation, factor endowments, and industry fixed effects, and reports the coefficient on institutions. Standard errors are clustered by importer×exporter pair (rows 1-8) or by country (row 9). Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 7: Roles of Other Industry Characteristics, Statistics Adjusted for Multiple Hypothesis Testing

	Association with clean index	Dependence of clean industries on institutions:			Comparative advantage of clean industries
		Financial	Judicial	Labor	
	(1)	(2)	(3)	(4)	(5)
Baseline	—	0.105	0.001	0.043	0.001
Energy share	0.003	0.105	0.001	0.064	0.001
Raw materials share	0.001	0.142	0.001	0.043	0.001
Upstreamness	0.001	0.105	0.001	0.072	0.001
Inverse export supply elasticity	0.001	0.176	0.001	0.099	0.001
Mean wage	0.009	0.126	0.001	0.101	0.001
Unemployment (%)	0.032	0.105	0.001	0.099	0.001
College educated	0.002	0.227	0.001	0.127	0.001
Union membership	0.001	0.105	0.001	0.107	0.001
Intra-industry share	0.032	0.142	0.001	0.099	0.001
Geographic dispersion	0.132	0.105	0.001	0.099	0.001
Labor share	0.001	0.105	0.001	0.127	0.001
Capital share	0.008	0.105	0.001	0.101	0.001
Log shipping cost per ton×km	0.001	0.380	0.001	0.173	0.001
Mean firm size	0.008	0.105	0.001	0.099	0.001
Std. dev. Firm size	0.044	0.105	0.001	0.099	0.001
Concentration ratio	0.032	0.105	0.001	0.099	0.001
Log output	0.132	0.105	0.001	0.099	0.001
Output trend 1977-2007	0.001	0.105	0.001	0.129	0.001
All at once	—	0.227	0.002	0.203	0.001

Notes: Each table entry shows the sharpened False Discovery Rate q-value using the method of Anderson (2008), which is analogous to a p-value adjusted for multiple hypothesis testing. Table entries and structure correspond to Table 4.

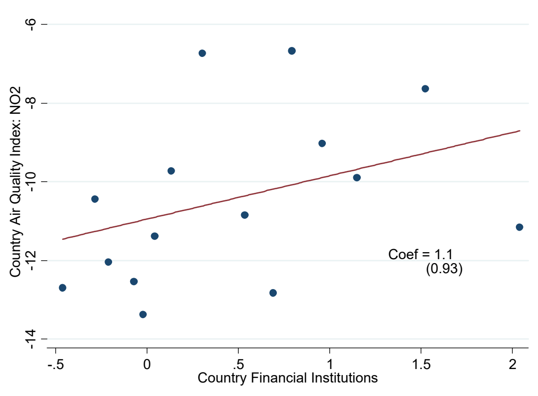
Appendix Table 8—Effects of Counterfactual Institutions, by Pollutant: Model-Based Analysis

Change in …	CO	NMVOC	NO_x	$PM_{2.5}$	SO_x
	(1)	(2)	(3)	(4)	(5)
Panel A. Counterfactual: remove institutional differences between countries					
Pacific Ocean	9.9%	1.8%	0.2%	2.8%	3.8%
Western Europe	1.9%	0.2%	-0.6%	0.8%	0.6%
Eastern Europe	-3.7%	-2.5%	-2.4%	-3.1%	-2.5%
Latin America	-14.1%	-5.8%	-4.6%	-12.1%	-11.4%
North America	3.6%	2.4%	1.0%	3.3%	1.8%
China	-1.4%	-0.8%	-0.7%	-0.8%	-0.8%
Southern Europe	-1.7%	-1.6%	-0.4%	-1.3%	-1.2%
Northern Europe	17.2%	5.3%	3.3%	8.6%	6.4%
Indian Ocean	-6.8%	-3.4%	-1.2%	-4.9%	-5.7%
Rest of World	-8.2%	-3.5%	-4.7%	-7.0%	-6.4%
Global	*-1.7%*	*-1.0%*	*-1.6%*	*-3.2%*	*-2.7%*
Panel B. Counterfactual: improve institutions in countries with below-median baseline institutions					
Pacific Ocean	8.2%	2.1%	1.3%	3.2%	3.9%
Western Europe	6.1%	2.4%	1.4%	3.6%	3.5%
Eastern Europe	-4.6%	-3.2%	-3.2%	-4.0%	-3.2%
Latin America	-16.9%	-6.7%	-5.5%	-14.3%	-13.5%
North America	3.8%	1.6%	2.0%	3.4%	2.2%
China	-3.9%	-2.2%	-1.9%	-2.5%	-2.4%
Southern Europe	6.8%	2.0%	1.3%	3.3%	2.4%
Northern Europe	9.6%	2.3%	2.0%	4.4%	3.1%
Indian Ocean	-8.4%	-4.1%	-1.5%	-6.2%	-7.2%
Rest of World	-10.4%	-4.1%	-5.0%	-9.0%	-8.0%
Global	*-3.2%*	*-1.5%*	*-1.5%*	*-4.5%*	*-3.8%*
Panel C. Counterfactual: improve institutions in Latin America					
Pacific Ocean	0.8%	0.2%	0.1%	0.2%	0.3%
Western Europe	0.7%	0.2%	0.2%	0.4%	0.3%
Eastern Europe	0.4%	0.1%	0.1%	0.3%	0.1%
Latin America	-24.1%	-9.1%	-6.0%	-20.8%	-19.0%
North America	1.6%	0.6%	0.7%	1.5%	0.9%
China	0.3%	0.1%	0.2%	0.4%	0.3%
Southern Europe	0.9%	0.2%	0.1%	0.4%	0.3%
Northern Europe	1.4%	0.3%	0.2%	0.6%	0.4%
Indian Ocean	0.4%	0.1%	0.1%	0.3%	0.2%
Rest of World	1.3%	0.4%	0.3%	1.2%	0.9%
Global	*-0.7%*	*-0.2%*	*-0.2%*	*-1.0%*	*-0.3%*

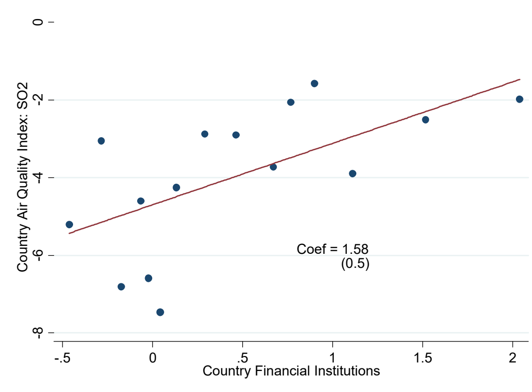
Notes: Table structure and entries are analogous to Table 5. This table shows percentage change in each air pollutant in Exiobiase, whereas Table 5 shows change in index of pollutants. CO is carbon monoxide, NMVOCs is non-methane volatile organic compounds, NO_x is nitrogen oxides, $PM_{2.5}$ is particulate matter smaller than 2.5 micrometers, and SO_x is sulfur oxides.

Appendix Figure 1. Country Environmental Quality and Country Institutions: Sensitivity

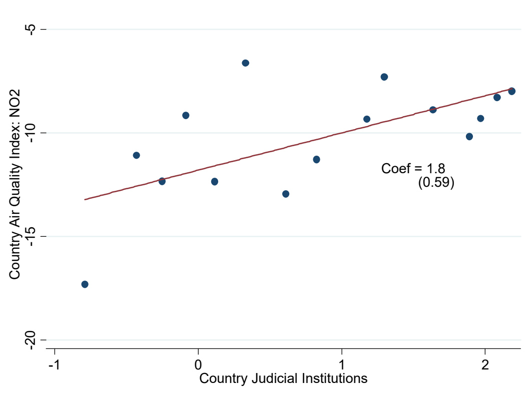
(A) Country NO_2 & financial institutions



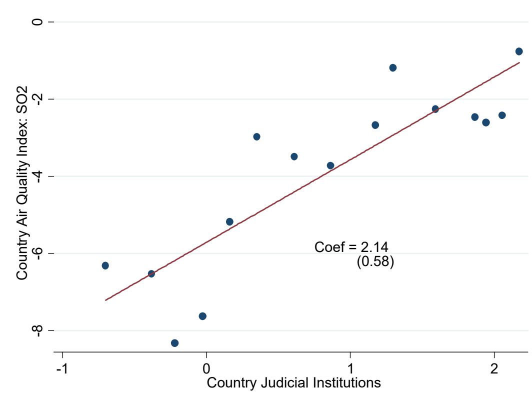
(B) Country SO_2 & financial institutions



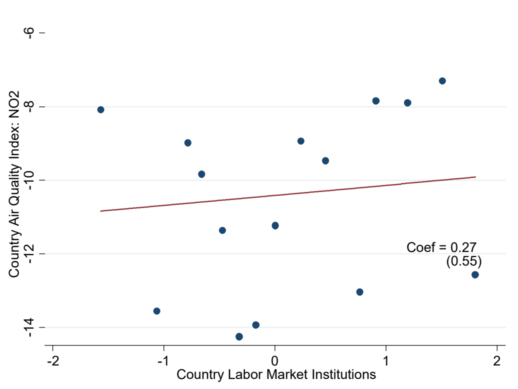
(C) Country NO_2 & judicial institutions



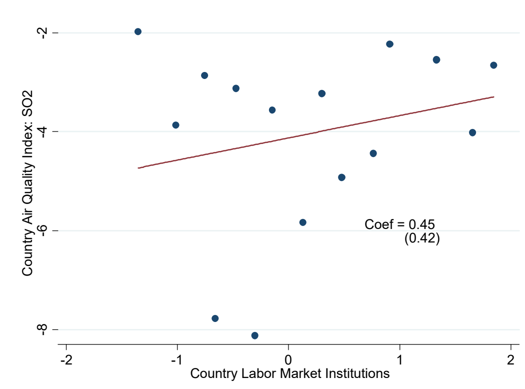
(D) Country SO_2 & judicial institutions



(E) Country NO_2 & labor market institutions



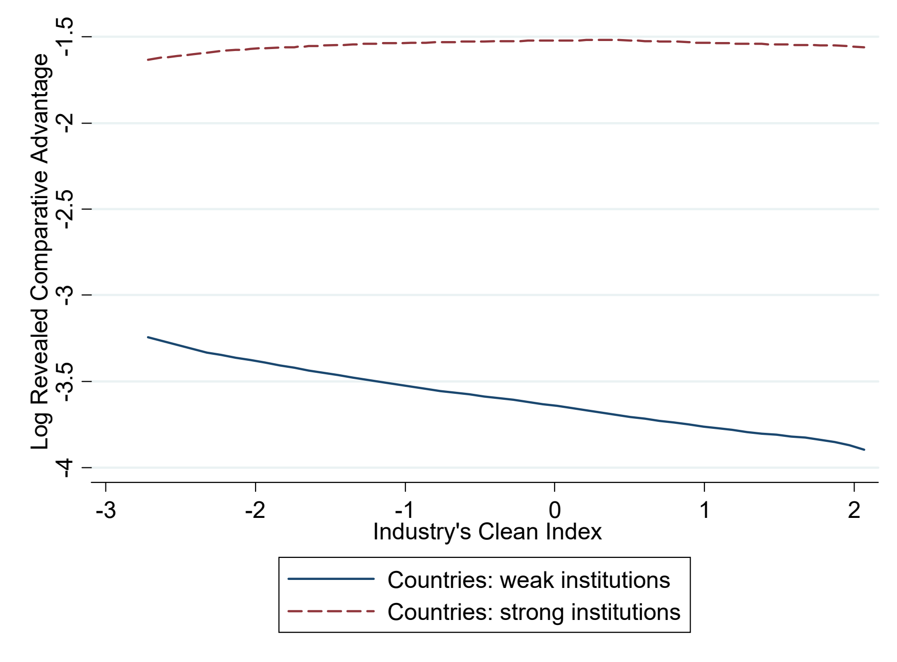
(F) Country SO_2 & labor market institutions



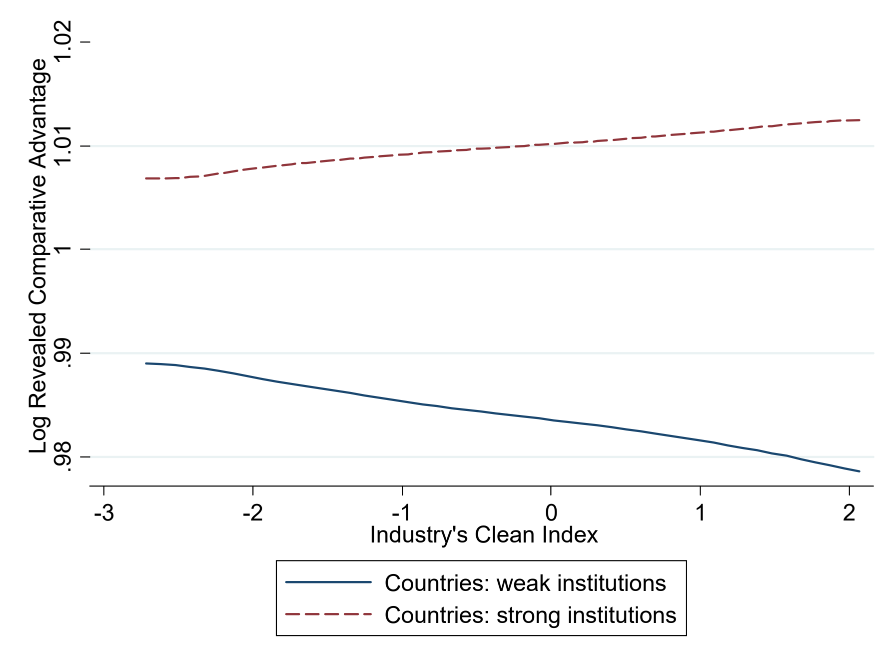
Notes: Graphs show binned scatter plots. Each observation in the underlying data represents a country. Within a country, air pollution data are averaged over available cities and years. Air quality equals minus one times the air quality index for the relevant pollutant. Blue circles are means of 15 evenly-sized country bins. Red line is linear fit. Institutions are in z-scores. Data from the World Air Quality Index (AQICN). NO_2 is nitrogen dioxide, a component of nitrogen oxides (NO_x); SO_2 is sulfur dioxide.

Appendix Figure 2. Industry Revealed Comparative Advantage and Exports, by Strength of Country Institutions

(A) Index of Balassa (1965)



(B) Index of Costinot, Donaldson, and Komunjer (2012)



Notes: "Countries: weak Institutions" includes the half of countries with below-median values of the institutions index, while "Countries: strong institutions" includes the half of countries with above-median values of the institutions index. Each graph shows two local linear regressions, with bandwidth of one. For each line, mean of log exports across industries are normalized to zero. Revealed comparative advantage is defined as a country's share of world exports in a sector divided by the country's share of world exports in all goods.

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