Institutions, Comparative Advantage, and the Environment*

Joseph S. Shapiro
UC Berkeley and NBER

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Abstract

This paper proposes that strong institutions provide comparative advantage in clean industries, and thereby improve a country's environmental quality. I study financial, judicial, and labor market institutions. Five complementary tests evaluate and assess implications of this hypothesis. First, industries that depend on institutions are clean. Second, strong institutions increase relative exports in clean industries. Third, an industry's complexity helps explain the link between institutions and clean goods. Fourth, cross-country differences in the composition of output between clean and dirty industries explain an important share of the global distribution of emissions. Fifth, 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. The comparative advantage that strong institutions provide in clean industries gives one under-explored reason why developing countries have relatively high pollution levels.

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1 Introduction

This paper proposes that strong institutions provide comparative advantage in clean industries. This mechanism, in addition to existing explanations focused on environmental regulation and factor endowments, provides an important and underappreciated contributor to global patterns of pollution. I define polluting industries as those with high emissions of air and water pollution per dollar of revenue, though consider alternative definitions.[1] I study financial, judicial, and labor market institutions.

I initially show that countries with stronger national institutions have better ambient air and water quality. This 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 affect 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 have disproportionately intangible assets which are more challenging than tangible assets to use as collateral, and thus clean industries disproportionately rely on financial institutions.

Second, stronger national institutions increase exports in clean industries. Institutions have large estimated impacts on pollution, with comparable importance for clean industries to 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 and panel, I study manufacturing or all industries, I compare across 15 measures of institutions and 8 measures of environmental regulation, I instrument institutions with historical natural experiments, I use US or multi-country data on pollution intensity, and I use intra-national data across states of India.

Third, clean industries depend on institutions because clean industries need sophisticated, skilled, and specialized inputs, i.e., complex inputs. These patterns help explain the first two parts' findings. Intuitively, dirty industries require large machines, plants, and other tangible assets to heat, pressurize, combust, and process raw materials like fossil fuels; this processing emits pollution as a waste byproduct and the collateral that these tangible assets provide decreases dirty industries' dependence on strong

[1] "Clean industries" in some settings denotes solar, wind, or other forms of energy generation besides fossil fuels. I use a broader interpretation of this phrase to describe any industry with relatively low pollution emissions per dollar of revenue.

financial institutions. Similarly, polluting industries disproportionately use fossil fuels, iron, and other homogeneous inputs which are traded on open exchanges and do not rely on complex bilateral contracts for judicial institutions to enforce. Clean industries rely on flexible labor market institutions, though to a lesser extent than on other institutions, in part because polluting goods like energy have inelastic short-run supply and demand, leading to less volatile sales and need for hiring and firing.

Fourth, I decompose how 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, this decomposition 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 covers all sectors, including but not restricted to manufacturing.

I find that composition has importance similar to or greater than technique in explaining cross-country 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 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 existing literature, reviewed below.

Fifth, 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 model parameters describing the productivity benefit of institutions, so the model is interpreting quantitative implications of the comparative advantage channels that the paper's earlier sections estimate. 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 the institutional quality in North America would decrease pollution in Latin America by up to 20 percent but increase pollution elsewhere, by relocating dirty industries.

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 reconciles results from the earlier regressions with prior literature. All five approaches address the same research question: how and why do institutions affect pollution through comparative advantage?

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, can improve national environmental quality through attracting clean industries.

If every country had Pigouvian taxes on all pollutants, this paper's findings would not change the national welfare consequences of institutions. To the extent that environmental policy is less stringent than optimal, especially in developing countries, this paper's findings strengthen the case for policies that improve institutions in developing countries, since this paper's results imply that such reforms help address environmental externalities. In many settings, political economy obstacles impede first-best environmental policy. Institutional reforms provide one second-best alternative. Additionally, when international organizations like the International Monetary Fund, World Bank, and bilateral aid organizations advocate for improving institutions, this paper suggests that such reforms can also help improve the environment. I also find that such reforms reallocate dirty production to high income countries, which complicates such reforms since primarily high-income countries fund the International Monetary Fund and World Bank.

Because the paper's mechanisms reshuffle pollution across countries, the paper does not find that policies improving institutions are an especially effective tool to reduce global pollution totals. At the same time, the questions of what forces contribute to the observed global distribution of environmental quality, or how improving institutions in one country affect the environment in that country, are important for research and policy, even if they do not identify a leading policy lever that decreases total global pollution. For example, the large impact of the Environmental Kuznets Curve literature (Grossman and Krueger 1995) partly reflects the high level of interest in explaining global patterns of environmental quality, even if the explanation does not immediately imply a single policy solution. Additionally, the fact that little if any existing economics research calculates the level of total global air pollution emissions suggests it is not the primary focus of existing research and policy. (Many sources do calculate global total greenhouse gas emissions, or analyze global ambient pollution concentrations.)

To clarify the paper's main ideas, consider a simple example. The Fluid Pumps industry, which builds hydraulic and pneumatic pumps used in industrial machines, emits little air or water pollution. The Gypsum Products industry, which produces drywall and plaster, emits high levels of air and water pollution. The cleaner industry in this example depends more on each type of institution. The cleaner (pumps) industry needs strong financial institutions, since a small share of its assets are tangible. The pumps industry also relies on judicial institutions, since it mainly uses specialized inputs like specialized machines that require bilateral contracts with suppliers. Finally, the pumps industry depends on flexible labor market institutions, since its annual sales change substantially in most years, which can require hiring or firing workers. In comparison, the dirtier (gypsum) industry relies less on financial institutions, since a large share of its assets are tangible. The dirtier gypsum industry primarily uses homogeneous inputs like coal, stone, and paperboard, which are traded on exchanges or through industry publications. Finally, the dirtier (gypsum) industry relies less on flexible labor market institutions, since its firms have steadier mean annual sales.[2]

This paper departs from existing work in several ways. I believe it is the first comprehensive analysis of how institutions affect environmental quality through comparative advantage. 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).[3] The idea that regions may use weak levels or enforcement of environmental policy to attract dirty industries (the "Pollution Havens Hypothesis") has widespread influence, and I build on literature seeking to understand the limited empirical support for this Hypothesis (Cherniwchan, Copeland and Taylor 2017).[4] 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, due to consumer preferences, structural transformation from agriculture to manufacturing to services, increasing returns to pollution abatement, or voting rules that determine environmental regulation (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 pollution is higher in developing countries for 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, and Haas and Popov (2018) relate a country's CO_2 per capita to its financial development. Unlike development-environment research, 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. Classic work emphasizes that property rights over natural resources increase investment (Coase 1960; Chichilnisky 1994).

This paper also shows that approaches in the trade literature used to study comparative advantage

[2]This example discusses NAICS industry codes 333996 and 327420.

[3]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.

[4]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).

can shed light on environmental quality. Research has studied how factor endowments (Romalis 2004), financial institutions (Rajan and Zingales 1998; Manova 2013) judicial institutions (Nunn 2007), and labor market institutions (Cuñat and Melitz 2012) drive international specialization (Chor 2010). 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. One explanation of this paper's conclusions is that they combine three fairly simple ideas—comparative advantage drives international trade (Chor 2010; Costinot and Donaldson 2012; Morrow 2022); institutions provide a source of comparative advantage; and 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.

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. This finding helps reconcile this paper's first three sections, which find that comparative advantage driven by institutions affects the global distribution of pollution, with previous literature, which finds that technique rather than composition drives most environmental change.

The decomposition also has relevance for the Environmental Kuznets Curve literature (Grossman and Krueger 1993). It is common to present graphs of an Environmental Kuznets Curve showing different countries at the same point in time. This paper highlights that technique effects may be comparatively important in the time series but composition may be relatively more important in the cross-section. Adapting analyses in the Environmental Kuznets Curve literature to test, accommodate, or study implications of possible cross-sectional and time-series differences may be informative.

Before proceeding, I clarify 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 trade papers on institutions mentioned earlier. 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 importance of environmental regulation. How could institutions, which do not purposefully target clean industries, have comparable importance as environmental policy, which targets dirty production? Cost structure provides an explanation. 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). Through changing the productivity of using intermediate goods or factors, however, institutions can change a majority of a firm's costs.

I proceed as follows. Section 2 describes data. Section 3 compares the clean index and dependence on institutions across industries. Section 4 estimates trade regressions interacting national institutions with an industry's clean index. Section 5 studies mechanisms. Section 6 decomposes scale, composition, and technique. Section 7 discusses a quantitative model of institutions and the environment. Section 8 concludes.

2 Data

Appendix Table 1 summarizes variables and Appendix A provides additional data 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.[5] I measure each institution 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

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

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; unlike principal components, these accommodate 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;[6] 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 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 large positive correlation. Labor market institutions have weaker positive correlation with other institutions. Environmental regulations 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.

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

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 for many countries based on technology estimates (Stadler et al. 2018). The variables used to explain 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.[7] 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 according to asset intangibility, measured as one minus the share of assets that are property, plant, and equipment in Compustat. Tangible assets can provide ready collateral for a loan, and so industries where most assets are tangible depend relatively less on financial institutions. 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 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 a focus of the trade-environment literature, and are feasible to attribute to individual industries. In the cross-section, relative emission rates across industries primarily reflect fixed attributes of each industry; for this reason, industries like primary metal processing, petroleum processing and refining, and pulp and paper mills are among the dirtiest industries in most time periods, papers, and datasets, ranging from the earliest discussions of pollution havens and the Clean Air Act a half century ago through more recent work (U.S. Department of Health, Education, and Welfare, Public Health Service 1967; Conroy 1974; Greenstone 2002), including Table 1 of this paper.

Specifically, 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

[7] 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.

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 *Base pour l'Analyse du Commerce International* (BACI) database, created by the *Centre d'Etudes Prospectives et d'Informations Internationales* (CEPII). I aggregate data to 134 individual countries with non-missing values of key variables, plus one rest-of-world region. I concord industries in these data to distinguish 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, and calibrate the quantitative model. Exiobiase is a multi-region input-output table, like the World Input Output Database or Eora. I use Exiobase since it has 163 industries, more than other world input-output tables.

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 previous research has reported it. It does not reveal causal evidence, since institutions may be correlated with other variables influencing pollution. It also provides no evidence on whether institutions affect pollution through comparative advantage or other channels.

Figure 1, which presents binned scatter plots of equation (1), shows that countries with stronger institutions have better air and water quality. Some relationships are roughly linear. Others are less robust. The financial and judicial institutional patterns are significantly different from zero, while the labor market institutional patterns are not. Panel E has a slight U shape reminiscent of the Environmental Kuznets Curve literature (Grossman and Krueger 1995). Appendix Figure 1 finds similar patterns for two other relevant pollutants that trade-environment research has examined—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. 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, as discussed in Section 2.2.

Table 1 describes the five cleanest and dirtiest manufacturing industries. Panel A shows that cleaner industries depend relatively more 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 more than the mean manufacturing industry does on financial, judicial, and labor market institutions. Panel B of Table 1 shows that dirtier industries depend less on institutions. For example, gypsum product manufacturing, one of the dirtiest manufacturing industries, depends less than the mean manufacturing industry does on all three types of institutions. 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 2.1 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. The upward-sloping lines show that cleaner industries depend more on stronger institutions. Panel A shows that industries that have relatively intangible assets, and thus depend relatively more on financial institutions, 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, so depend more on flexible labor market institutions, are cleaner. As shown in the R-squared in the three graphs, the clean index explains a third of the variation in dependence on financial institutions, a fourth of the variation in judicial institutions, and little of the variation in labor market institutions.

This section finds that the industries which depend on institutions are clean. Existing research finds that strong national institutions provide comparative advantage in industries that depend on institutions. Combining these two results indirectly implies that institutions provide comparative advantage in clean industries. The next section interacts country and industry characteristics to test directly for comparative advantage in clean industries.

4 Regressions: Direct Tests of Comparative Advantage

4.1 Comparative Advantage in All Industries

As Section 7 discusses, 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 level, $c_{i,s}$ 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:

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

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

$$ln\xi - \theta_s lnc_{i,s} - \theta_s ln\phi_{ij,s} = \gamma ln(1 + t_{ij,s}) + \eta_{ij} + \omega_{ij,s} \tag{6}$$

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

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 $\omega_{i,s}$.[8] 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.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.

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

$$lnX_{ij,s} = \alpha E_i I_s + \sum_f \beta_f E_i^f I_s^f + \pi R_i Z_s + \gamma ln(1 + t_{ij,s}) + \zeta_{j,s} + \eta_{ij} + \epsilon_{ij,s} \tag{8}$$

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 exporter, as in Defever, Head and Larch (2015); Do, Levchenko and Raddatz (2016), and Gerritse (2021). 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

[8] Institutions and factors affect technology $T_{i,s}$ rather than the unit cost $c_{i,s}$ because the unit cost only depends on prices and model parameters. Appendix Equation (D–5) shows that the cost function $c_{i,s}$ depends on the price of labor and intermediate goods. Put another way, institutions and factors via the industry-specific interaction terms in $T_{i,s}$ determine how much output a unit of inputs can generate; and the cost function $c_{i,s}$ describes the price of a unit of inputs.

and Tenreyro 2006). 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 potential econometric issues. Institutions may be measured with error, correlated with other country characteristics, and affected by trade and production. To address 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.

Should estimates of equations like (8) include additional interactions, such such as the interaction of an industry's clean index with the country's GDP per capita? One might think that such additional controls could help address omitted variables bias. At the same time, theoretical and empirical reasons argue against such controls. Theoretically, this kind of GDP interaction is not readily derived from a standard closed-form gravity model, whereas most of the other regressions are consistent with the kind of model the paper later discusses and analyzes quantitatively. GDP is an endogenous outcome of all countries' endowments, industries' intensities, and parameters in a general equilibrium model, whereas the regressions derived from the model include predetermined country endowments that determine comparative advantage. Econometrically, since institutions and factors affect log GDP per capita, the GDP interaction is a bad control in the sense of Angrist and Pischke (2009), since GDP per capita is an intermediate outcome that institutions affect. Despite these caveats, I do report one sensitivity analysis which interacts the log of GDP per capita with each industry's clean index.

More broadly, how should we interpret the effect of institutions? An empirical interpretation is that while institutions are not randomly assigned, the various cross-section, panel, and instrumental variables estimates represent the thought experiment of randomly changing the quality of a country's institutions, while holding other attributes of the country fixed, and holding fixed attributes of other countries. These estimates represent the effect of such random variation in a country's institutions on its production of clean versus dirty goods and other outcomes. A model-based interpretation, which justifies the use of these regressions for calibrating the quantitative model, is that institutions change the fundamental productivity $T_{i,s}$ of a country in certain industries, and these regressions estimate the magnitude of that relationship.

Results

Table 2, Panel A, examines comparative advantage in a standard setting, corresponding to equation (8). It finds 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 0.057 standard deviations. In other words, this indicates that financial institutions provide a source of comparative advantage. Columns (2) through (4) show that similar patterns hold for other institutions, though the relationship for labor is statistically insignificant. Column (5) shows that environmental regulation provides a source of comparative advantage in clean industries. 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 magnitudes across variables. 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 relevant to trade and comparative advantage broadly.

These estimates for the comparative advantage of institutions are qualitatively in line with existing papers. As in Chor (2010), each of the three institutions has some role individually, and factor endowments and institutions matter independently. In Chor (2010), judicial institutions matter the most either when the three institutions are analyzed in separate regressions or together, while here, financial institutions matter slightly more. The magnitudes here are smaller than corresponding estimates in Nunn (2007) or Chor (2010), perhaps in part because this paper has more countries, industries, and detailed controls.

One explanation for the 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. This pattern again demonstrates the relevance of environmental policy in explaining comparative advantage overall.

4.2 Comparative Advantage in Clean Industries

The findings in Section 4.1 and previous work that institutions provide comparative advantage, and in Section 3 that the industries benefiting 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.

Results

Figure 3, Panels A and B, graph 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 regions with strong versus weak institutions. 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 region. The upward-sloping dashed line in Panel A indicates that Switzerland exports more in clean than dirty industries. 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 is economically large.

Figure 3, Panel B, finds similar patterns for all countries. This panel separates 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. 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 the measure of Costinot, Donaldson and Komunjer (2012) than in that of Balassa (1965).

Table 2, Panel B, estimates equation (9). It 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. In the regressions separating the three institutions in column (9), only financial institutions are statistically significant, though all have positive coefficients that are similar to or larger than the coefficient for environmental regulation.

It is unclear what existing evidence would predict regarding this greater role for financial institutions in clean production. Figure 2 finds that dependence on financial institutions has the strongest correlation with an industry's clean index, closely followed by dependence on judicial institutions. Appendix Table 2 also finds that financial 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). Existing work does highlight the direct importance of financial institutions for clean production (Andersen 2016, 2017; Haas and Popov 2018).

Panel B of Table 2, 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 (5) supports the Pollution Havens Hypothesis by finding that environmental regulation drives specialization in clean industries. Column (10) finds that institutions are at least as important as environmental regulation to explaining countries' specialization in clean versus 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 (9) and (10), suggests that this counterfactual would decrease a country's emissions by about 25 percent. This calculation makes strong assumptions. It only analyzes traded manufacturing goods. It assumes other sources of technology, factors, and determinants of specialization are fixed. It assumes institutions have log-linear effects, and it comes from a partial equilibrium calculation. The quantitative model in Section 7 helps relax these assumptions.

A second interpretation of Panel B of Table 2, column (10), observes that the coefficient on institutions is just under half 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 4 to 7 percentage points. This would

[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.

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 large changes in trade policy.

4.3 Alternative Research Designs and Sensitivity Analyses

Panel Data Estimates

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

$$lnX_{ij,sy} = \alpha^P E_{i,y} Z_s + \sum_f \beta_f^P E_{i,y}^f I_s^f + \zeta_{j,sy}^P + \eta_{ij,y}^P + \epsilon_{ij,sy}^P \quad (11)$$

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-difference version of equation (11), with years 2000 and 2015.[10] 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 (11) 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 (11) estimate the short-run relationship. The long-difference estimate obtains medium-run estimates.[11]

Although a country's institutions have path dependence, the mean country has reasonable-sized 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.[12] Institutions improved in about two-thirds of countries and worsened in a third of countries. 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.

[10] I use 2000 rather than 1996 for the first year of the long-difference estimate since the data coverage is much lower in 1996 than in 2000.

[11] I investigated how changes in the institutional quality of a country's trading partners affect the country's own specialization in dirty industries. I concluded that this setting lacks sufficient statistical power to quantify these general equilibrium spillovers with meaningful precision, since the resulting estimates did not rule out economically meaningful impacts of either sign.

[12] 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.

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

Appendix Table 3, row 2, exploits panel variation in institutions, capital, labor, and other variables within a country and over 20 years, corresponding to equation (11). Row 3 uses the long difference sample in 2000 and 2015. The panel data estimate obtains precise results, with smaller magnitudes in the full panel but larger magnitudes in the long-difference estimates. The comparative advantage that institutions provide in clean industries is 0.038 (0.012) in the baseline estimates, 0.013 (.005) in the full panel estimates, and 0.062 (0.031) in the long-difference estimates. The smaller magnitude of the full panel versus long difference is consistent with measurement error in institutions. It is also consistent with the idea that trade responds gradually to institutions.

Cross-State, Intranational Institutions

I also compare institutions across states within a single country, India. Comparing across states within a country helps address the concern that some determinants of specialization may vary across countries in ways that are difficult to observe. I study India since its 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. One limitation is that India only has 28 states, 26 with data available.

Appendix Table 3, row 4, estimates comparative advantage due to institutions across states in India. The magnitude of the overall comparative advantage of institutions in column (1), and the comparative advantage that institutions provide in clean industries in column (2), are both moderately larger than the global baseline estimate from row 1. The global and intra-national India estimates differ in several ways, including the use of trade versus production data and different measures of institutions and controls. While this makes it difficult to provide an apples-to-apples comparison, these magnitudes 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 Additional Sensitivity Analyses

Appendix B discusses a range of sensitivity analyses, which largely leave qualitative conclusions unchanged. These include varying data sources and econometric assumptions, including controlling for interactions of the exporter's log GDP per capita and an industry's clean index, and estimating the relationship between institutions and clean production techniques within an industry (Appendix Table 3); alternative measures of environmental regulation (Appendix Table 4); using other measures of institutions, including historical instrumental variables for institutions (Appendix Table 5); and using randomization inference (Appendix Figure 3).

Appendix Table 3, rows 16-20, includes interactions of a country's institutions with both the clean industry index and the measures of each industry's dependence on institutions in the same regression. In other words, it combines the main explanatory variables from Table 2, Panels A and B, into a single regression. In most of these estimates, the interaction of institutions with the clean industry index becomes small and statistically insignificant, although the financial interactions term remains marginally significant. These estimates are generally in line with the paper's interpretation that institutions encourage specialization in clean industries primarily because clean industries depend on institutions. This is why controlling for the country institutions $\times$ industry dependence term attenuates the coefficient on country institutions $\times$ industry clean index. Of course, the empirical measures of each industry's dependence on institutions are proxies which may have some degree of measurement error, and which may account for the positive but small coefficients on some of the country institutions$\times$industry clean index terms in these regressions.

5 Explanations

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

5.1 Intuitive Explanations

Intuitively, why do clean industries depend on financial institutions? Polluting industries, often described as "heavy industry," use large, long-lived, tangible assets like machines and boilers to process and convert dense raw materials into finished products. Plant-level increasing returns may contribute to these industries' large investments in tangible assets. The tangibility of dirty industries' assets provides collateral that helps these industries borrow money even in settings with weak financial institutions. For example, cement is among the dirtiest manufacturing industries and has large plant-level returns to scale, partly because cement kilns are among the world's largest pieces of industrial machinery (Norman 1979; Ganapati, Shapiro and Walker 2020). To give other examples, cracking units in oil refineries, blast furnaces for metal smelting, ammonia synthesis in chemical manufacturing, ethylene production at petrochemical plants, and many other polluting industrial processes require temperatures near or far above 1,000 degrees Fahrenheit and immense pressure. Intangible assets like patents, copyrights, trademarks, or brand equity cannot safely generate such physical chemical reactions, which is why the dirty industries using such reactions rely disproportionately on tangible assets.

Why do clean industries depend on judicial institutions? Dirty industries disproportionately use raw materials that are homogeneous because natural processes form identical materials under identical conditions across the planet. Many raw materials used in dirty industries' production, like the iron used to make steel or the lead used to manufacture batteries, are elements of the periodic table that consist of one type of atom present throughout the Earth's crust. Because these inputs are homogeneous, they are not exchanged through specialized contracts that depend on judicial institutions to enforce, but instead are bulk commodities that can be traded through open markets. Put another way, if one considered factors embodied in value chains of intermediate inputs, the complex inputs used in clean industries intensively use clean factors like skills and intellectual property, while the simpler inputs used in dirty industries intensively use dirty factors like fossil fuels, metals, and related natural resources.

The estimated relationship between an industry's clean index and its dependence on labor market institutions is weaker than the relationships I find for financial and judicial institutions, and correspondingly, I believe the intuition for clean industries' dependence on labor market institutions is less direct. Regardless, an intuitive explanation is that polluting industries like energy produce goods with inelastic short-run supply and demand, partly because these goods are necessities. Economies buy energy-intensive and dirty goods year after year, making these industries less likely to hire and fire workers each year. Cleaner goods may have more elastic short-run demand and thus more volatile sales that require hiring and firing workers.

5.2 Statistical Explanations

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

$$Z_s = \rho_0^W + \rho_1^W W_s + \epsilon_s^W \tag{12}$$

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 an industry's clean index with the industry's dependence on institutions:

$$Z_s = \rho_0^{IW} + \rho_1^{IW} I_s + \rho_2^{IW} W_s + \epsilon_s^{IW} \tag{13}$$

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:

$$lnX_{ij,s} = \alpha^W E_i Z_s + \alpha^W E_i W_s + \sum_f \beta_f^W E_i^f I_s^f + \pi^W R_i Z_s + \gamma^W t_{ij,s} + \zeta_{j,s}^W + \eta_{ij}^W + \epsilon_{ij,s}^W \tag{14}$$

Table 3, column (1), shows that clean and dirty industries differ along many dimensions. Clean industries have more processed, complex inputs. Specifically, clean industries have lower cost shares of energy and raw materials, more differentiated products (higher inverse export supply elasticity), lower shipping costs, and are less upstream. Echoing some of the intuitive explanations from the previous subsection, an industry's energy share, raw materials share, and shipping cost have the strongest associations with the clean index.

Table 3, 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 (13). They show that differentiated, processed, and downstream industries are clean and depend on institutions. The most important industry characteristics here again are the industry's energy shares and shipping costs. No one industry characteristic alone fully accounts for most of 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 3 estimates equation (14). The last row of Table 3 controls for all these variables at the same time. Again, no single variable completely accounts for the comparative advantage that strong institutions provide in clean industries. An industry's raw materials share and shipping costs account for meaningful shares of the comparative advantage of clean industries; and including all variables together accounts for about 25 percent of this comparative advantage. Given the many hypothesis tests in Table 3, Appendix Table 6 obtains similar conclusions from p-values adjusted for multiple hypothesis testing (Anderson 2008).

Appendix Table 7 repeats this analysis but controls for variables cumulatively. Each row in Appendix Table 7, in other words, controls for the indicated variable, in addition to all variables listed in earlier rows. The qualitative conclusions are similar, although point estimates vary somewhat from those of Table 3, especially for variables further down in the table which in Appendix Table 7 have more controls from earlier rows.

Appendix Table 8 examines the importance of industry characteristics for comparative advantage of clean industries, separately for each type of institution. It obtains similar findings that the energy and raw materials shares, shipping costs, and related variables account for much of the clean-institutions relationship. As in much of the paper, these patterns are clearer for financial and judicial than for labor market institutions.

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 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.

The paper could conclude here, and has already used several methods to test its hypothesis. An important consideration, 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 the previous sections 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—existing decompositions look within a country and over time, and largely avoid cross-country contemporaneous 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 previous sections with existing literature which finds little role for composition.

6 Decomposing Scale, Composition, and Technique

I decompose pollution in a cross section of countries as follows. 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.[13]

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

$$\mathcal{E} = \sum_s \mathcal{E}_s = \sum_s x_s e_s = X \sum_s \kappa_s e_s \tag{15}$$

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

$$\frac{d\mathcal{E}}{\mathcal{E}} = \frac{dX}{X} + \frac{d\kappa}{\kappa} + \frac{de}{e} \tag{16}$$

The first term on the right of (16) represents scale, the second represents composition, and third represents technique.

Research typically takes equation (16) 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 in order to distinguish scale, composition, and technique effects. I implement this comparison for each country

[13] I treat a 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.

i separately:

$$Scale_{i,r} = \frac{\sum_s x_{is}}{\sum_s x_{rs}} \tag{17}$$

$$Composition_{i,r} = \frac{\sum_s \kappa_{is} e_{rs}}{\sum_s \kappa_{rs} e_{rs}} = \frac{\sum_s \kappa_{is} e_{rs}}{Z_r/X_r} \tag{18}$$

$$Technique_{i,r} = \frac{\sum_s \kappa_{is} e_{is}}{\sum_s \kappa_{is} e_{rs}} = \frac{Z_i/X_i}{\sum_s \kappa_{is} e_{rs}} \tag{19}$$

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 (17) through (19), I subtract one, so the results can be interpreted as the percentage change in pollution relative to the reference country. Appendix C derives equations (18)-(19) from equations used in prior literature that compares within a country and over time.

The scale effect in (17) 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 the emissions per unit output within an industry were identical across countries.

The composition effect in equation (18) equals the difference in emission rates between countries i and r due to the difference in the share of output κ from each industry between the two countries. The composition effect 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).

The technique effect in equation 19 equals the difference in emissions between countries i and r due to the difference in emission rates e from each industry. Equation (19) uses weights from the focal country κ_{is} for consistency with the existing 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}). 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.[14] 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

[14] 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 (17) 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 (18) 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 (19) 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 much less output than the US economy (scale effect), it emits more sulfur both because it is more concentrated in polluting industries (composition effect) and because a given industry emits more pollution in India (technique effect). Here, composition accounts for 43 percent (=162/(162+216)) of the composition+technique total.

Table 4 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, a proportion which varies across pollutants from 45 to 89 percent. 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 concentrate production more in dirty industries 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.or lower than the US (i.e., the US and other countries have the same means, but larger differences in absolute 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 from comparing the US to other countries.

Figure 4 describes the distribution of the ratio $|Composition|/(|Composition| + |Technique|)$ across all possible country pairs. 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 (17), (18), and (19) 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 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 discussed earlier, which finds that technique explains much of the time series change in pollution within country and over time, one might expect technique rather than composition to account for most of this difference.

Appendix Figure 4 separately shows this comparison for several important countries—China, Germany, India, and the US. For example, Panel A of Appendix Figure 4 shows all country pairs where China is the focal or reference country. Although the panels of Appendix Figure 4 reveal modest differences – for example, India has more outlier comparisons where technique plays a relatively smaller or larger role, while the US has fewer – these panels have similar overall patterns.

Is the variation in these graphs mostly driven by reference countries or by differences across focal countries for a given reference country? As one indication, I regress the $|Composition|/(|Composition|+|Technique|)$ ratio from the data underlying Appendix Figure 4 on reference country fixed effects, focal country fixed effects, or both, in a dataset where each observation is a country pair. I find that reference country fixed effects obtain an R-squared of 0.37, focal country fixed effects obtain an R-squared of 0.14, and both together obtain an R-squared of 0.50. Thus, in comparing across country pairs, half the variation in the relative importance of composition comes from features specific to the individual countries, while the remaining half reflects pairwise interactions.

Why does Figure 4 find a large role for composition, while prior literature finds a larger role for technique? One reason is that Figure 4 compares across countries and within a time period, while prior literature looks within a country and over time. A less immediate explanation is that the effectiveness of pollution control technologies like scrubbers or selective catalytic reduction mean that a source can decrease its pollution emissions by more than 95 percent almost immediately, while a country's institutions change less rapidly. Although institutions do have a reasonable degree of variation within country and over time, as described earlier, institutions also have a reasonable degree of persistence. This is one reason the legal origins, settler mortality, and year 1500 population density instruments discussed in the appendix strongly predict institutions today.

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. Because these are decompositions and not regressions, the aforementioned findings do not reflect differences in regression assumptions about omitted variables bias, 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. To give one point of reference, 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.

How do this section's decompositions quantitatively relate to the analysis of institutions in earlier sections? Appendix Table 9 finds that across countries, national financial and judicial institutions, though not labor market institutions, are correlated with cleaner industrial composition. This table calculates the mean composition effect from equation (18) for each focal country, across all reference countries. One could interpret this as the percentage pollution differential that this country experiences relative to other countries due to differences in industrial composition. I report a cross-sectional regression of this composition value on the national institutions values. Panels A and B indicate that countries with strong financial and judicial institutions have significantly cleaner industrial composition. Panel C finds insignificant and positively signed patterns for labor market institutions. Panel D finds that judicial institutions have the strongest negative correlation with composition effects. The institutions index in Panel E is negatively correlated with composition effects, though precision varies by pollutant. Because each cross-sectional correlation has 46 observations without any research design or other countries, these estimates do not represent a causal relationship, and I therefore interpret them cautiously.

7 Counterfactual Institutions: Model-Based Estimates

The previous sections find that institutions provide comparative advantage in clean industries, that industry complexity provides an important explanation, and that differences in the industrial composition of output across countries account for an important share of differences in pollution. 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$\times$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.

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

$$\hat{T}_{i,s} = exp\left\{\alpha I_s(E_i^{'} - E_i)\right\} \tag{20}$$

To estimate equation (20), 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. I then choose $E_i^{'}$ to define a counterfactual. Equation (20) is the only part of the model which uses information on institutions. I therefore emphasize the caveat that the model-based analyses of counterfactuals hold fixed any effect that institutions have on productivity or pollution intensity that is uniform across industries. The counterfactual analyses therefore reflect differences in effects of institutions across industries, in line with the paper's focus on comparative advantage.

Country i's 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 dollar of revenue, $R_{i,s}$ describes country×sector revenue, and $c_{i,s}$ is the unit cost function. In baseline data, $\gamma_{i,s}$ equals the units of pollution per dollar of revenue. Counterfactuals can change revenues $R_{i,s}$ and costs $c_{i,s}$, so I interpret changes in $R_{i,s}/c_{i,s}$ as real revenue, with $c_{i,s}$ as the deflator. 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 muted technique regression estimates discussed 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

$$\hat{\mathcal{E}}_i = \frac{\sum_s (\hat{R}_{i,s}/\hat{c}_{i,s})\mathcal{E}_{i,s}}{\sum_s \mathcal{E}_{i,s}} \tag{21}$$

where $\mathcal{E}_{i,s}$ is the baseline observed pollution for a country×sector. Equation (21) means 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.

I apply the model empirically 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. With far more detailed regions or industries, the algorithm for analyzing counterfactuals does not always converge. The quantitative model uses sector-specific trade elasticities aggregated across four studies (Caliendo and Parro 2015; Shapiro 2016; Giri, Yi and Yilmazkuday 2020; Bagwell, Staiger and Yurukoglu 2021; see also Bartelme et al. 2021 and Shapiro 2021).[15]

Counterfactuals and Results

I study five 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. The fourth counterfactual improves institutions in all regions by half a standard deviation. The fifth counterfactual changes each region's institutions by the observed, historical improvement in the region's institutions between 1996 and 2015.

Table 5 shows effects of these counterfactuals. 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

[15] The sectors and elasticities appear in Appendix Table 7, column (1) of Shapiro (2021), and range from 2.99 to 13.53 across sectors.

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. Columns (4) through (6) 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 by around 10 percent. Columns (4) through (6) show that these changes come from reallocating production between clean and dirty industries in each country.

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.

Panel D of Table 5 analyzes the fourth counterfactual, which improves institutions in each region by half a standard deviation. I choose this magnitude since it approximates the mean absolute value change in institutions for all countries between 1996 and 2015 and is a typical absolute value change from Panels A through C. Although this counterfactual improves institutions in all regions, it decreases pollution in some regions and increases it in others, since the effect of institutions on pollution operates through reshuffling dirty industries globally.

One might expect that the equal improvements in institutions from Panel D of Table 5 for all regions would cancel out and have no effect on region-specific pollution, again since pollution changes due to reshuffling industries. Equation (20) from the main text and equations (D–7) through (D–8) from the appendix show, however, that changes in institutions have nonlinear effects on production and pollution which interact with baseline country endowments. For example, while equation (D–6) shows that the change in expenditure shares $\hat{\lambda}_{ij,s}$ is proportional to the change in institutions, counterfactual patterns of bilateral trade $\lambda'_{ij,s}$ equal the baseline expenditure shares multiplied by the change in institutions. Partly because this counterfactual decreases the proportional difference in institutions across countries with strong and weak baseline institutions, it slightly equalizes pollution across regions. The signs of most countries' change in emissions echo those of the first counterfactual which equalizes emissions globally. The magnitudes here, however, are smaller.

Panel E of Table 5 calculates the mean change in institutions for each region between 1996 and 2015, where I take the export-weighted mean across countries within each region. I then change each region's institutions by this amount. This counterfactual provides a benchmark for how institutional changes over the last two decades affected environmental quality. Because it averages across countries within a region, the institutional changes for each region are not especially large. Column (2) shows that institutions have improved most in China and in Eastern and Northern Europe. Column (3) finds that these have decreased pollution emissions by several percent. Institutions slightly deteriorated in the Indian Ocean region (India and Indonesia), and emissions correspondingly increased.

Appendix Table 10 shows effects of these counterfactuals on each air pollutant in Exiobase separately. Most counterfactuals have the same sign impact on global emissions across all these pollutants, although magnitudes differ. For example, particulate matter smaller than 2.5 micrometers ($PM_{2.5}$) changes more than non-methane volatile organic compounds (NMVOCs) globally in most counterfactuals, perhaps in part because more of NMVOCs comes from transportation, which is less widely 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 the location of emissions since they depend on population density, wind, and many other variables.

Decreasing a country's emissions via technique effects will typically decrease global emissions. Decreasing a country's emissions via composition effects, however, has ambiguously-signed effects on global emissions, since the composition effect is likely to reshuffle dirty industries to other countries. The counterfactual results clearly show this channel, since improving institutions in countries with weak initial institutions reduces emissions in those countries but increases them in other countries. Because dirty industries have lower emissions intensity in countries with strong baseline institutions, I do find that this global reallocation decreases total global pollution. At this same time, it is worth highlighting that this general equilibrium effect dampens the effect of institutions on global emissions that one might calculate from the reduced-form regressions earlier in the paper. For this reason, this paper's findings do not change the received wisdom from the literature that if the primary goal of analysis or policy is decreasing global emissions, then reforms that change technique may be most effective. At the same time, if the primary goal of analysis or policy is explaining or decreasing one country's emissions, then composition effects become more relevant.

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 (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 institutions to operate efficiently, and so disproportionately locate in countries with strong institutions. Quantitatively, institutions have similar importance to 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 historical natural experiments. Financial and to a lesser extent judicial institutions seem most important to the location choices of clean industries; flexible labor market institutions play a less central role.

Does this paper overturn priors about how institutions and pollution interact? Because that interaction has limited existing research, my interpretation is that before this paper, most economists did not have a prior about this interaction. This paper is probably leading people to create such a prior more than overturning existing priors.

How important is the general idea that an industry's dependence on institutions may be correlated with other socially valuable or costly attributes? For example, what if industries that depend more on institutions are more gender equal, or involve fewer workplace injuries? Would such findings meaningfully change the analysis of institutions, gender equality, or workplace injuries? I believe the basic concept this paper proposes lacks previous application—economic endowments like institutions can have meaningful effects on market failures like externalities through correlation across industries in externalities' dependence on institutions. While this idea need not be applied to numerous other market failures, the general idea is important and the welfare consequences of environmental externalities makes them a powerful setting to demonstrate the idea's importance.

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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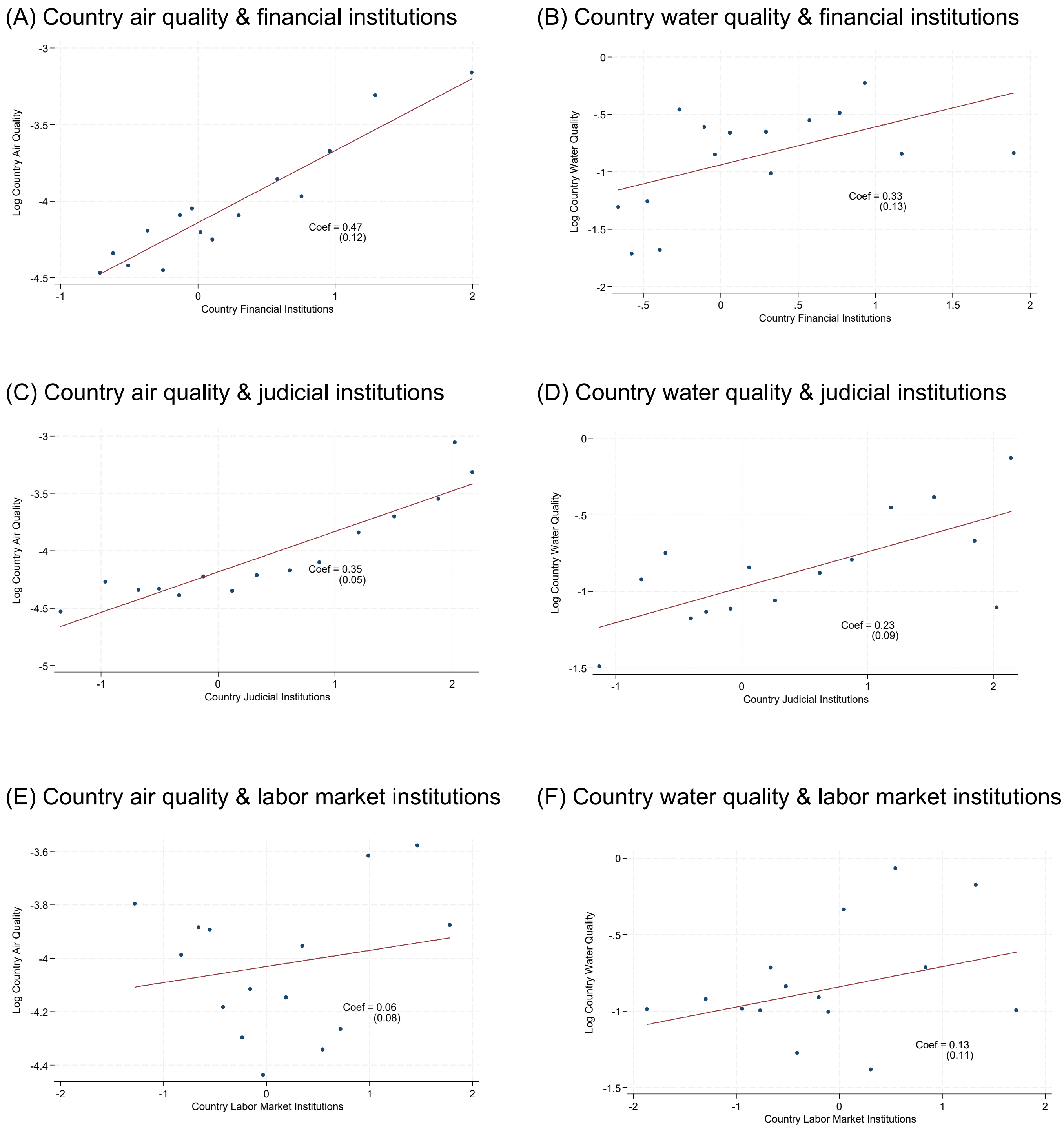
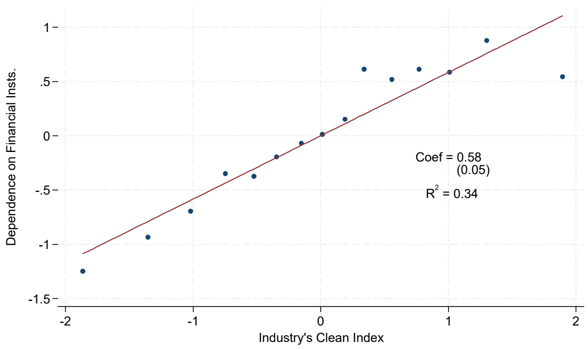
Figure 1. Country Environmental Quality and Country Institutions



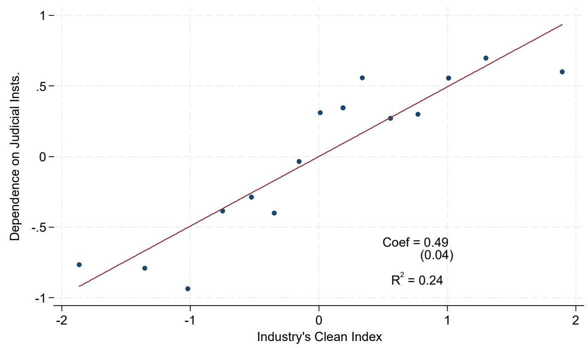
Notes: Graphs show binned scatterplots—blue circles are means of 15 bins, each with approximately equal number of countries. Red line is linear trend. Log of country environmental quality is negative one times the log of the country's mean $PM_{2.5}$ in μg/m^3 (Panels A, C, and E); or times the log of the country's mean biochemical oxygen demand in mg/L (Panels B, D, and F). "Coef" shows line slope and its robust standard error. Institutions are in z-scores. The number of observations for Panels A through F, in order, is as follows: 86, 66, 88, 66, 82, and 66.

Figure 2. Industry Dependence on Institutions and Industry Clean Index

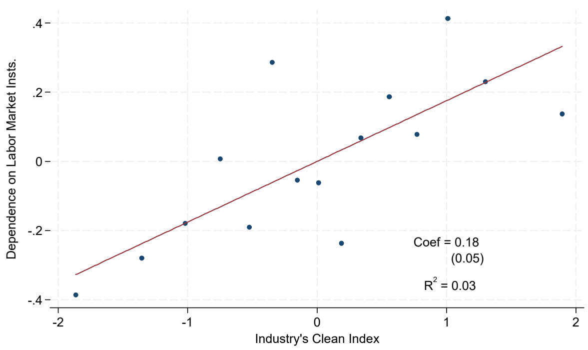
(A) Financial institutions



(B) Judicial institutions



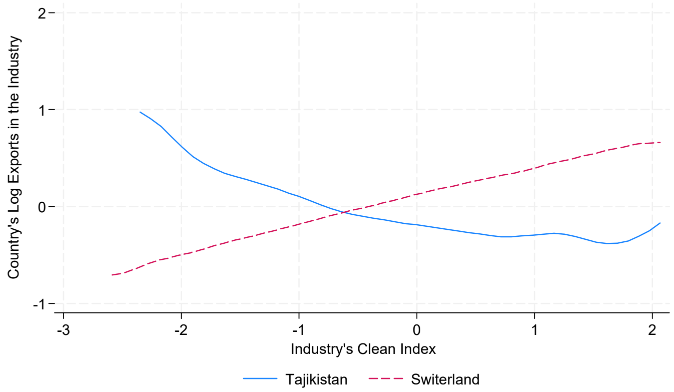
(C) Labor market institutions



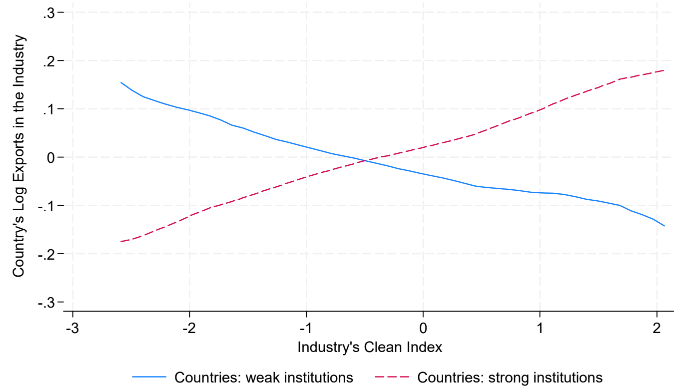
Notes: Graphs show binned scatterplots─blue circles are means of 15 bins, each with equal number of industries. Each observation in the underlying data represents a manufacturing industry. Blue circles show means of 15 bins, each with an equal number of countries. Red line is linear fit. Dependence on institutions variables are in z-scores.

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

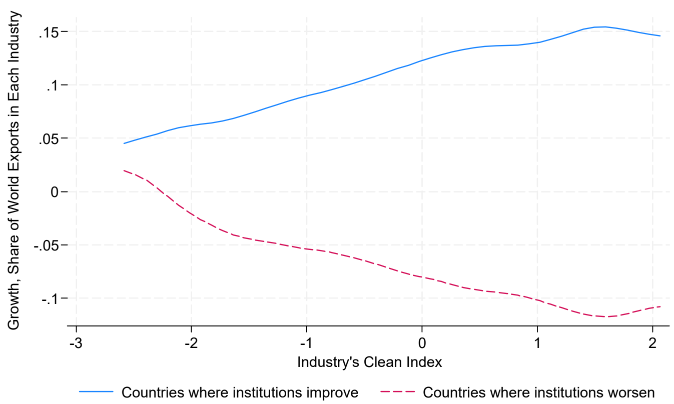
(A) Two country comparison



(B) Many country comparison

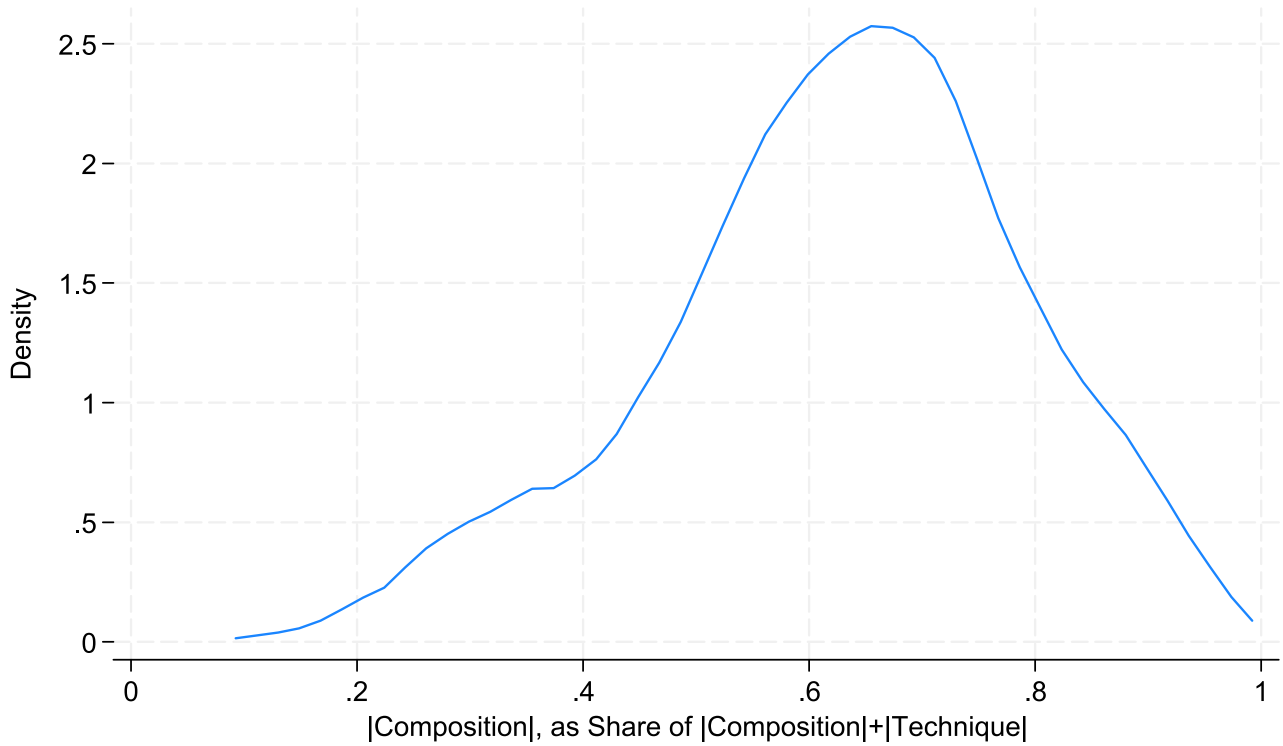


(C) Panel Data, 1996-2015



Notes: in Panel A, Tajikistan has weak institutions and 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 first principal component 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 Country Pairs



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 focal countries while using *r* as reference, divided by |*composition*|+|*technique*| averaged across all countries while using *r* as reference. Each underlying point averages across (r,i) and (i,r) country pairs (e.g., US-China and China-US), and across air pollutants in Exiobase. Calculations cover all industries. Pollution emission rates are winsorized at the 99.9th percentile and calculation excludes industry×year cells with less than $10,000 in annual sales.

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	0.68	0.07	0.22	0.35
Instruments for industrial processes	2.58	1.48	1.18	-0.59	1.16
Fluid power pumps and motors	2.42	0.21	0.66	1.00	0.80
Curtain and linen mills	2.40	0.53	0.54	1.51	0.98
Precision turned product manufacturing	2.23	-0.61	0.15	0.19	-0.07
Mean for cleanest industries	*2.46*	*0.46*	*0.52*	*0.47*	*0.65*
Panel B. Dirtiest industries					
Aluminum refining and production	-2.17	-1.84	-1.63	-0.96	-2.03
Gypsum product manufacturing	-2.18	-2.19	-1.16	-1.18	-1.91
Pulp mills	-2.22	-2.08	-0.48	-0.09	-1.10
Newsprint mills	-2.30	-3.12	-0.60	-0.80	-1.76
Other petroleum, coal products	-2.43	0.10	-1.26	0.96	-0.55
Mean for dirtiest industries	*-2.26*	*-1.83*	*-1.03*	*-0.41*	*-1.47*

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

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.	0.057***	—	—	—	—	—	—	—	0.036**	—
	(0.012)	—	—	—	—	—	—	—	(0.015)	—
Institutions: judicial	—	0.054***	—	—	—	—	—	—	0.025**	—
	—	(0.010)	—	—	—	—	—	—	(0.010)	—
Institutions: labor	—	—	0.006	—	—	—	—	—	0.004	—
	—	—	(0.004)	—	—	—	—	—	(0.004)	—
Institutions: index	—	—	—	0.057***	—	—	—	—	—	0.038***
	—	—	—	(0.007)	—	—	—	—	—	(0.008)
Environmental reg.	—	—	—	—	0.048***	—	—	—	0.017*	0.022**
	—	—	—	—	(0.009)	—	—	—	(0.010)	(0.009)
Factor capital/lab.	—	—	—	—	—	-0.025	—	—	0.186**	0.172*
	—	—	—	—	—	(0.096)	—	—	(0.089)	(0.098)
Factor: skills	—	—	—	—	—	—	0.348***	—	0.282***	0.285***
	—	—	—	—	—	—	(0.036)	—	(0.035)	(0.033)
Log(1+tariffs)	—	—	—	—	—	—	—	-0.085***	-0.084***	-0.085***
	—	—	—	—	—	—	—	(0.009)	(0.009)	(0.009)
Panel B: Comparative advantage in clean industries										
Country endowment × clean industry index:										
Institutions: financ.	0.051***	—	—	—	—	–	–	–	0.035**	—
	(0.010)	—	—	—	—	–	–	–	(0.015)	—
Institutions: judicial	—	0.054***	—	—	—	–	–	–	0.008	—
	—	(0.010)	—	—	—	–	–	–	(0.031)	—
Institutions: labor	—	—	0.018**	—	—	–	–	–	0.006	—
	—	—	(0.008)	—	—	–	–	–	(0.008)	—
Institutions: index	—	—	—	0.054***	—	–	–	–	—	0.038***
	—	—	—	(0.007)	—	–	–	–	—	(0.012)
Environmental reg.	—	—	—	—	0.048***	–	–	–	0.008	0.008
	—	—	—	—	(0.009)	–	–	–	(0.028)	(0.014)
Country endowment × industry intensity:										
Factors capital/lab.	—	—	—	—	–	-0.025	–	–	0.112	0.115
	—	—	—	—	–	(0.096)	–	–	(0.086)	(0.094)
Factors: skills	—	—	—	—	–	–	0.348***	–	0.307***	0.302***
	—	—	—	—	–	–	(0.036)	–	(0.034)	(0.034)
Log(1+tariffs)	—	—	—	—	–	–	–	-0.085***	-0.084***	-0.085***
	—	—	—	—	–	–	–	(0.009)	(0.009)	(0.009)
Fitted effect 10→90%	-20.5%	-38.1%	-14.8%	-34.5%	–	–	–	–	-21.4%	-24.7%
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. N=1,875,532. 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 exporter. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Table 3—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	—	0.58***	0.49***	0.18***	0.041***
	—	(0.05)	(0.04)	(0.05)	(0.010)
Energy share	-0.37***	0.50***	0.42***	0.16***	0.042***
	(0.12)	(0.05)	(0.04)	(0.05)	(0.010)
Raw materials share	-0.36***	0.49***	0.33***	0.17***	0.031***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.009)
Upstreamness	-0.35***	0.48***	0.37***	0.17***	0.049***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.010)
Inverse export supply elasticity	0.27***	0.61***	0.50***	0.15**	0.048***
	(0.06)	(0.06)	(0.05)	(0.06)	(0.011)
Mean wage	0.06	0.57***	0.49***	0.17***	0.037***
	(0.06)	(0.04)	(0.04)	(0.05)	(0.010)
Unemployment (%)	-0.08*	0.58***	0.49***	0.16***	0.038***
	(0.04)	(0.05)	(0.04)	(0.05)	(0.010)
College educated	0.18***	0.53***	0.46***	0.16***	0.033***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.009)
Union membership	-0.28***	0.51***	0.48***	0.16***	0.043***
	(0.05)	(0.04)	(0.04)	(0.05)	(0.009)
Intra-industry share	0.06	0.66***	0.56***	0.15**	0.050***
	(0.06)	(0.06)	(0.05)	(0.06)	(0.011)
Geographic dispersion	-0.03	0.59***	0.50***	0.17***	0.041***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.010)
Labor share	0.29***	0.58***	0.43***	0.17***	0.048***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.011)
Capital share	-0.06	0.58***	0.50***	0.17***	0.041***
	(0.09)	(0.05)	(0.04)	(0.05)	(0.010)
Log shipping cost per ton×km	-0.41***	0.51***	0.44***	0.10	0.038***
	(0.07)	(0.06)	(0.06)	(0.07)	(0.008)
Mean firm size	-0.10**	0.57***	0.48***	0.17***	0.042***
	(0.04)	(0.05)	(0.04)	(0.05)	(0.010)
Std. dev. Firm size	-0.12**	0.58***	0.49***	0.17***	0.042***
	(0.06)	(0.05)	(0.04)	(0.05)	(0.010)
Concentration ratio	-0.15***	0.59***	0.49***	0.17***	0.040***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.010)
Log output	-0.06	0.58***	0.48***	0.18***	0.044***
	(0.04)	(0.05)	(0.04)	(0.05)	(0.011)
Output trend 1977-2007	-0.15***	0.60***	0.51***	0.16***	0.039***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.010)
All at once	—	0.19***	0.12**	0.05	0.031***
	—	(0.05)	(0.06)	(0.10)	(0.008)

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 exporter in column (5). Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Table 4—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	-0.45	-0.67	-0.89
	(0.70)	(0.67)	(0.35)	(1.53)	(0.87)	(0.19)
2. Scale	-0.89	—	—	—	—	—
	(0.19)	—	—	—	—	—
3. Composition	1.75	1.20	2.11	2.75	2.11	0.55
	(1.23)	(1.21)	(1.46)	(1.98)	(2.23)	(0.55)
4. Technique	-0.02	0.10	-0.36	0.25	0.20	-0.32
	(0.59)	(0.76)	(0.44)	(1.07)	(1.19)	(0.31)
5. |Composition|	1.76	1.24	2.11	2.77	2.11	0.59
	(1.21)	(1.17)	(1.45)	(1.95)	(2.23)	(0.51)
6. |Technique|	0.47	0.51	0.49	0.74	0.88	0.38
	(0.36)	(0.57)	(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. CO is carbon monoxide, NO_x is nitrogen oxides, $PM_{2.5}$ is particulate matter smaller than 2.5 micrometers, SO_x is sulfur oxides, and VOCs are volatile organic compounds.

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 (%)	Dirty industries	Moderate industries	Clean industries
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Counterfactual: remove institutional differences between countries						
Pacific Ocean	1.9	-1.0	3.7%	1.2%	0.2%	-1.4%
Western Europe	1.3	-0.4	0.7%	0.3%	0.0%	-0.3%
Eastern Europe	0.2	0.6	-2.8%	-0.9%	-0.3%	1.2%
Latin America	-0.6	1.5	-11.0%	-1.3%	-0.8%	2.1%
North America	2.4	-1.6	2.9%	0.7%	0.4%	-1.1%
China	0.7	0.2	-1.0%	-0.3%	-0.2%	0.5%
Southern Europe	0.7	0.1	-1.4%	-0.3%	-0.1%	0.4%
Northern Europe	2.2	-1.4	7.8%	1.6%	0.7%	-2.3%
Indian Ocean	-0.3	1.2	-5.3%	-0.9%	-0.1%	1.0%
Rest of World	0.2	0.7	-6.1%	-1.0%	-0.6%	1.6%
Global	—	—	*-2.6%*	—	—	—
Panel B. Counterfactual: improve institutions in countries with below-median baseline institutions						
Pacific Ocean	1.9	0.0	3.7%	0.8%	0.1%	-1.0%
Western Europe	1.3	0.0	3.5%	0.7%	0.1%	-0.8%
Eastern Europe	0.2	1.5	-3.6%	-0.9%	-0.3%	1.2%
Latin America	-0.6	2.4	-13.1%	-1.4%	-0.7%	2.1%
North America	2.4	0.0	2.5%	0.4%	0.2%	-0.5%
China	0.7	1.1	-2.9%	-0.6%	-0.1%	0.7%
Southern Europe	0.7	0.0	3.0%	0.7%	0.1%	-0.8%
Northern Europe	2.2	0.0	3.9%	0.6%	0.2%	-0.8%
Indian Ocean	-0.3	2.0	-6.6%	-0.8%	0.2%	0.6%
Rest of World	0.2	1.6	-7.5%	-1.0%	-0.2%	1.2%
Global	—	—	*-3.7%*	—	—	—
Panel C. Counterfactual: improve institutions in Latin America						
Pacific Ocean	1.9	0.0	0.4%	0.1%	0.0%	-0.1%
Western Europe	1.3	0.0	0.4%	0.1%	0.0%	-0.1%
Eastern Europe	0.2	0.0	0.2%	0.1%	0.0%	-0.1%
Latin America	-0.6	3.1	-18.5%	-2.1%	-0.9%	3.0%
North America	2.4	0.0	1.0%	0.1%	0.1%	-0.2%
China	0.7	0.0	0.3%	0.1%	0.0%	-0.1%
Southern Europe	0.7	0.0	0.4%	0.1%	0.0%	-0.1%
Northern Europe	2.2	0.0	0.5%	0.1%	0.0%	-0.1%
Indian Ocean	-0.3	0.0	0.3%	0.1%	0.0%	-0.1%
Rest of World	0.2	0.0	0.9%	0.1%	0.0%	-0.2%
Global	—	—	*-0.9%*	—	—	—

(Continued next page)

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

		Counterfactual change in…		Change: share output from…		
	Baseline institutions (z-score)	Institutional quality (z-score)	Emissions (%)	Dirty industries	Moderate industries	Clean industries
	(1)	(2)	(3)	(4)	(5)	(6)
Panel D. Counterfactual: improve institutions in all countries equally						
Pacific Ocean	1.9	0.5	*0.7%*	-0.2%	-0.1%	0.2%
Western Europe	1.3	0.5	*0.3%*	-0.2%	0.0%	0.2%
Eastern Europe	0.2	0.5	*-0.4%*	0.1%	0.1%	-0.2%
Latin America	-0.6	0.5	*-3.1%*	-0.2%	0.0%	0.2%
North America	2.4	0.5	*1.2%*	0.0%	-0.1%	0.0%
China	0.7	0.5	*-2.3%*	-0.4%	0.1%	0.3%
Southern Europe	0.7	0.5	*0.2%*	0.0%	0.0%	0.1%
Northern Europe	2.2	0.5	*0.0%*	-0.2%	-0.2%	0.4%
Indian Ocean	-0.3	0.5	*-1.6%*	0.1%	0.3%	-0.4%
Rest of World	0.2	0.5	*-1.7%*	-0.1%	0.4%	-0.3%
Global	—	—	*-1.4%*	—	—	—
Panel E. Add 1996-2015 changes in institutions						
Pacific Ocean	1.9	0.0	*1.2%*	0.3%	0.0%	-0.3%
Western Europe	1.3	0.0	*1.1%*	0.2%	0.0%	-0.2%
Eastern Europe	0.2	0.5	*-1.1%*	-0.3%	0.0%	0.3%
Latin America	-0.6	0.1	*-0.1%*	0.0%	0.0%	0.0%
North America	2.4	0.0	*0.8%*	0.1%	0.1%	-0.2%
China	0.7	0.8	*-3.2%*	-0.7%	-0.1%	0.9%
Southern Europe	0.7	-0.1	*1.1%*	0.3%	0.0%	-0.3%
Northern Europe	2.2	0.6	*-2.8%*	-0.6%	-0.3%	0.9%
Indian Ocean	-0.3	-0.2	*1.8%*	0.4%	0.0%	-0.4%
Rest of World	0.2	0.1	*0.7%*	0.1%	0.1%	-0.2%
Global	—	—	*-0.7%*	—	—	—

Notes: institutional quality is first 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.

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, sensitivity analyses 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 analyses using panel data, because labor market institutions data are only available for the period 2005-2016, I assume labor market 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 industry-level emissions data with better quality than almost most other countries. The NEI is collected every three years, so I use data from the 2011 edition, which is the closest to year 2012. Across pollutants, 80-95 percent of NEI emissions are reported with a 6-digit NAICS code, 2-17 percent with a 5-digit NAICS code, and 1 to 2 percent report a more aggregate industry code. In some cases, the 5-digit codes in fact represent a 6-digit NAICS code without the trailing zero explicitly listed. I measure pollution for each 6-digit NAICS code in the analysis using the most detailed industry code available from the NEI. Because such a small share of the data report aggregated NAICS codes, this is unlikely to be quantitatively important.

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.

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.

To define each industry's reliance on labor market institutions, I define sales volatility using all available years of Compustat data. I limit the sample to firms present in at least five years, with absolute value of growth below 300%, and in industries with at least 10 firms.

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 3 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. Rows 2 through 4 show panel, long-difference, and intra-national estimates using data from India, all discussed in Section 4.3.

Appendix Table 3, Row 5, reports panel estimates where the clean index varies over time within industry, using data from the 1999 and 2014 NEI, though institutions are fixed at the level analyzed in the rest of the paper. The resulting comparative advantage estimate is statistically indistinguishable from zero, with negative point estimate.

Why does this panel estimate not find impacts of changes in an industry's clean index over time on production? This result is consistent with the idea that environmental regulation drives much of the change in emissions intensity within an industry and over time, and that such regulation does not affect the fundamental characteristics of an industry which determine its dependence on institutions. End-of-pipe pollution control technologies like scrubbers, and substitution between high-and low sulfur coal, play a central role in explaining longitudinal changes in an industry's clean index (Carlson et al. 2000; Fowlie 2010; Fowlie, Holland and Mansur 2012; Deschenes, Greenstone and Shapiro 2017). Such technologies are unlikely to affect an industry's dependence on institutions. For example, while cement factories increasingly use effective end-of-pipe pollution control devices, these devices do not change the industry's dependence on bulk commodity inputs like limestone and fossil fuels; pollution control devices are also unlikely to affect the industry's sales volatility or need for labor market flexibility; and such devices are also unlikely to affect the share of industry's capital that is tangible.

Appendix Table 3, rows 6 through 15, present several other sensitivity analyses. Row 6 includes all industries, not only manufacturing. Row 7 uses Exiobase. Row 8 estimates the regression in levels, including zero trade flow observations, using Poisson pseudo maximum likelihood (Silva and Tenreyro 2006). 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 (B–1). Row 10 includes all three institutions simultaneously. Row 11 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 12 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 13 adds a control for the interaction of the exporter's log of GDP per capita with the clean industry index. Row 14 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 15 adjust standard errors for two-way clustering within both exporter and industry.

Most of these sensitivity analyses in Appendix Table 3 obtain results that are qualitatively similar to the main estimates, though magnitudes vary across samples and specifications, and some details are important. Most of 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 increases the importance of institutions overall and for clean industries. The Exiobase sample, with far fewer industries than the main sample, has larger magnitude for clean industries but lower precision. Rows 16-20 discuss estimates that simultaneously control for interactions of a country's institutions with an industry's dependence on institution and the industry's clean index; the main text discusses these results. The largest point estimates are from using PPML and Exiobase.

The randomization inference estimate in Appendix Figure 3 shows that comparative advantage estimates from the main text are unlikely to occur by chance. For 1,000 separate iterations, I randomly reshuffle (i.e., draw without replacement) institutions across countries, randomly reshuffle the clean index across industries, then repeatedly estimate the comparative advantage parameter α^C from equation (9) using the reshuffled data. The empirical distribution of these estimates obtains a bell-curve shaped distribution about zero, with the highest randomly obtain parameter estimate of just under 0.01. By contrast, the vertical red line shows that the actual parameter estimate from the un-reshuffled true data, as reported in Table 2, Panel B, column (10), is 0.04. This use of randomization inference echoes its application in other trade research (Dingel, Meng and Hsiang 2019; Gerritse 2021).

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:

$$Z_{is} = \alpha^T E_i + \sum_f \beta_f E_i^f + \pi R_i \eta_s + \mu_s + \epsilon_{is} \tag{B–1}$$

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 3, row 9, estimates an imprecise zero effect of institutions on clean production techniques for a country×industry. 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.

B.1 Other Measures of Environmental Regulation

Appendix Table 4 obtains similar estimates of the comparative advantage equations (8) and (9) using different measures of environmental regulation. Row 1 transforms 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. Row 2 measures 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 country institutions×clean industry interactions have coefficients between 0.03 and 0.06 and are statistically distinct from zero at 95 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.

B.2 Other Measures of Institutions

Appendix Table 5, rows 1-12, 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, and 5 alternative measures of labor market institutions.

In column (1) of Appendix Table 5, most estimates imply that institutions provide a source of comparative advantage. In column (2), most measures of institutions provide comparative advantage in clean industries. Magnitudes and precise vary across the individual some specific measures of institutions, which is one reason to focus on more aggregate measures.

B.3 Historical Instruments for Institutions

Several econometric reasons lead me to report estimates that use historical instrumental variables for institutions. 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$\times$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$\times$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.

A final reason for this analysis is that judicial institutions can have multiple interpretations, one as a way to protect citizens from expropriation by the executive or other centralized powers, and another as a way to secure contracts between citizens. As in Acemoglu and Johnson (2005), I explore the use of multiple instruments to distinguish these two channels.

I study three sets of historical instruments. One uses colonial settler mortality, a second uses year 1500 population density, and the third uses the origin of a country's legal system. I take data directly from research proposing these instruments Acemoglu, Johnson and Robinson (2001, 2002); Djankov et al. (2003), and build on other work applying them (Acemoglu and Johnson 2005; Lerner and Schoar 2005; Nunn 2007). Scholars have debated the interpretation and importance of some of these instruments (e.g., La Porta, Lopez de Silanes and Shleifer 2008). For example, 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 5, rows 13 through 21, reports 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. 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.

Estimates in rows 13-21 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. 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.

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:

$$\text{Scale} = \frac{X_i}{X_r} \tag{C–2}$$

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

$$\text{Scale+Composition+Technique} = \frac{X_i \sum_s \kappa_{is} e_{is}}{X_r \sum_s \kappa_{rs} e_{rs}} = \frac{\mathcal{E}_i}{\mathcal{E}_r} \tag{C–4}$$

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–2) 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 (17). Scale+Composition (C–3) 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–4), 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 (18), equals Scale+Composition in equation (C–3) divided by Scale in equation (C–2):

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

The technique effect from the main text, in equation (19), equals Scale+Composition+Technique from equation (C–4), divided by Scale+Composition from equation (C–3):

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

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

$$c_{i,s} = \xi_2 w_i^{1-\alpha_{i,s}} \prod_k P_{i,k}^{\alpha_{i,ks}} \tag{D–5}$$

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

$$\hat{\lambda}_{ij,s} = \hat{T}_{i,s} \left(\frac{\hat{c}_{i,s}\hat{\phi}_{ij,s}}{\hat{P}_{j,s}} \right)^{-\theta_s} \tag{D–6}$$

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

$$\hat{c}_{i,s} = \hat{w}_i^{1-\alpha_{i,s}} \prod_k \hat{P}_{i,k}^{\alpha_{i,ks}} \tag{D–7}$$

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

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

$$\hat{R}_{i,s} = \frac{\sum_j X'_{ij,s}}{\sum_j X_{ij,s}} \tag{D–8}$$

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

$$\sum_s \hat{y}_{i,s}y_{i,s} = 1 \tag{D–9}$$

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 2.5 micrometers (PM_{10}) and biochemical oxygen demand (BOD)	World Air Quality Index (AQICN); Global Environmental Monitoring System for freshwater (GEMStat)
Panel B. Industry level variables		
Institution intensity: financial	Share of assets that are not plant, property, or equipment.	Compustat North America. Used in Manova (2013).
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 l'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	0.62	1.00	—	—	—	—	—
Institutions: labor	0.17	0.01	1.00	—	—	—	—
Institutions: index	0.82	0.90	0.35	1.00	—	—	—
Factor intensity: capital	-0.38	-0.43	-0.16	-0.48	1.00	—	—
Factor intensity: skills	0.41	0.27	0.09	0.36	0.00	1.00	—
Clean index	0.58	0.49	0.18	0.59	-0.47	0.31	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—Sensitivity Analyses for Institutions and Comparative Advantage

Industries:	All	Clean
	(1)	(2)
1. Baseline estimates	0.038***	0.038***
	(0.008)	(0.012)
N	1,875,532	1,875,532
2. Full panel	0.013**	0.013**
	(0.005)	(0.005)
N	28,488,568	28,488,568
3. Long difference	0.054*	0.062**
	(0.032)	(0.031)
N	3,054,038	3,054,038
4. Intra-national: across states of India	0.104***	0.075***
	(0.010)	(0.009)
N	6,328	6,328
5. Longitudinal changes in clean industry index	—	-0.004
	—	(0.006)
	—	684,360
6. All industries, not just manufacturing	0.045***	0.044***
	(0.009)	(0.014)
N	1,915,625	1,932,690
7. Exiobase	0.007	0.055
	(0.030)	(0.044)
N	88,843	88,843
8. Poisson pseudo maximum likelihood	0.115***	0.057*
	(0.031)	(0.033)
N	4,072,672	4,072,672
9. Institutions and technique	0.005	—
	(0.041)	—
N	6,320	—
10. All institution interactions at once		
Financial institutions	0.037**	0.035**
	(0.014)	(0.015)
Judicial institutions	0.025**	0.008
	(0.010)	(0.031)
Labor market institutions	0.005	0.006
	(0.004)	(0.008)
N	1,875,532	1,875,532

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Appendix Table 3—Other Sensitivity Analyses for Institutions and Comparative Advantage (Continued)

Industries:	All	Clean
	(1)	(2)
11. Trade frictions, not i,j FE	0.037***	0.039***
	(0.008)	(0.012)
N	1,771,902	1,771,902
12. Leontief Inverse matrix	—	0.036***
	—	(0.008)
N	—	1,861,040
13. Control for exporter log GDP per cap	0.054***	0.048***
* industry clean index	(0.017)	(0.015)
N	1,836,774	1,836,774
14. Indicator for dirtiest industries	—	0.039***
	—	(0.007)
N	—	1,875,532
15. Two-way cluster by exporter and industry	0.038***	0.038***
	(0.010)	(0.013)
N	1,875,532	1,875,532
16. Interact country financial institutions with indsutry clean index and financial intensity		
Country financial institutions ×	—	0.034***
industry financial intensity	—	(0.010)
Country financial institutions ×	—	0.018*
industry clean index	—	(0.010)
N	—	1,875,532
17. Interact country judicial institutions with industry clean index and judicial intensity		
Country judicial institutions ×	—	0.033***
industry judicial intensity	—	(0.008)
Country judicial institutions ×	—	0.018
industry clean index	—	(0.032)
N	—	1,875,532
18. Interact country labor market institutions with industry clean index and labor market intensity		
Country labor market institutions ×	—	0.005
industry labor market intensity	—	(0.004)
Country labor market institutions ×	—	0.010
industry clean index	—	(0.006)
N		1,875,532

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Appendix Table 3—Other Sensitivity Analyses for Institutions and Comparative Advantage (Continued)

Industries:	All	Clean
	(1)	(2)
19. Interact each country institution with industry clean index and each institution intensity		
Country financial institutions ×	—	0.028**
industry financial intensity	—	(0.011)
Country judicial institutions ×	—	0.025***
industry judicial intensity	—	(0.009)
Country labor market institutions ×	—	0.005
industry labor market intensity	—	(0.004)
Country financial institutions ×	—	0.019*
industry clean index	—	(0.010)
Country judicial institutions ×	—	-0.002
industry clean index	—	(0.030)
Country labor market institutions ×	—	0.006
industry clean index	—	(0.008)
N	—	1,875,532
20. Interact country institution index with industry clean index and institution intensity index		
Country institutions index ×	—	0.032***
industry institutions index intensity	—	(0.007)
Country institutions index ×	—	0.019
industry clean index	—	(0.012)
N	—	1,875,532

Notes: In most rows, column (1) shows the coefficient on country institution endowment×industry institution intensity and column (2) shows the coefficient on country institution endowment×industry clean index. Each table entry shows beta coefficients from a separate regression. Unless otherwise noted, cross-sectional regressions control for importer×exporter FE, importer×industry FE, factor endowments×factor intensity, environmental regulation×pollution intensity, and log(1+tariffs). Row 6 assumes non-manufacturing industries have mean capital and labor levels. Row 7 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 exporter. 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	0.037***	0.032***
	(0.008)	(0.010)
Environmental regulation mean percentile	0.087***	0.061**
	(0.020)	(0.029)
N	1,875,532	1,875,532
2. Institutions index	0.038***	0.033***
	(0.008)	(0.010)
Environmental regulation mean z score	0.028***	0.020**
	(0.007)	(0.009)
N	1,875,532	1,875,532
3. Institutions index	0.042***	0.056***
	(0.008)	(0.017)
Environmental enforcement	0.01	-0.014
	(0.010)	(0.018)
N	1,875,532	1,875,532
4. Institutions index	0.040***	0.045***
	(0.008)	(0.014)
Environmental stringency	0.016	-0.002
	(0.010)	(0.016)
N	1,875,532	1,875,532
5. Institutions index	0.045***	0.042***
	(0.008)	(0.007)
Environmental treaties	0.011*	0.007
	(0.006)	(0.006)
N	1,875,532	1,875,532
6. Institutions index	0.041***	0.042***
	(0.009)	(0.009)
Air quality std. for particulates	0.006	0.002
	(0.010)	(0.011)
N	1,667,912	1,667,912
7. Institutions index	0.039***	0.040***
	(0.009)	(0.008)
Air quality std. for sulfur dioxide	0.006	0.003
	(0.008)	(0.008)
N	1,616,724	1,616,724
8. Institutions index	0.036***	0.029**
	(0.009)	(0.011)
Gasoline standard for lead	0.038***	0.032**
	(0.011)	(0.013)
N	1,602,505	1,602,505

Continued next page

Appendix Table 4—Comparative Advantage: Other Measures of Regulation (Continued)

9. Institutions index	0.039***	0.032***
	(0.007)	(0.008)
Diesel standard for sulfur	0.037***	0.031***
	(0.011)	(0.012)
N	1,875,532	1,875,532
10. Institutions index	0.042***	0.038***
	(0.009)	(0.008)
Environmental taxes / GDP	0.005	0.004
	(0.007)	(0.006)
N	1,625,106	1,625,106

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 log(1+tariffs). Standard errors are clustered by exporter. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 5—Comparative Advantage: Other Institution Measures

Industries:	All (1)	Clean (2)
Country financial institutions interactions		
1. IMF financial development	0.062***	0.062***
	(0.013)	(0.019)
N	1,869,578	1,869,578
2. IMF financial markets	0.054***	0.050***
	(0.013)	(0.015)
N	1,869,578	1,869,578
3. World Bank credit institutions	0.093**	0.057
	(0.047)	(0.040)
N	1,875,532	1,875,532
Country judicial institutions interactions		
4. Fraser Institute judicial institutions	0.139***	0.09
	(0.035)	(0.120)
N	1,875,532	1,875,532
5. World Bank number of procedures	0.074*	0.023
	(0.044)	(0.042)
N	1,875,532	1,875,532
6. World Bank number of days	0.017	-0.004
	(0.020)	(0.018)
N	1,875,532	1,875,532
7. World Bank percent cost	0.007	0.004
	(0.010)	(0.012)
N	1,875,532	1,875,532
Country labor market institutions interactions		
8. ILO labor protection	0.02	0.008
	(0.012)	(0.026)
N	1,652,326	1,652,326
9. Doing Business Report--rigidity	0.003	0.025*
	(0.006)	(0.013)
N	1,875,532	1,875,532
10. World Economic Forum efficiency	0.045**	0.083
	(0.021)	(0.052)
N	1,872,994	1,872,994
11. Botero et al. (2004)	0.008	0.050***
employment laws	(0.010)	(0.016)
N	1,678,353	1,678,353

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Appendix Table 5—Comparative Advantage: Other Measures of Institutions (Continued)

Industries:	All (1)	Clean (2)
12. Botero et al. (2004)	0.014	0.012
collective relations laws	(0.010)	(0.027)
N	1,678,353	1,678,353
Constraint on executive versus credit market institutions		
13. Constraint on the executive	0.087	0.030
	(0.055)	(0.061)
N	1,867,472	1,867,472
14. Constraint on the executive:	0.145	0.107
settler mortality IV	(0.154)	(0.174)
N	816,673	816,673
15. Constraint on the executive:	0.586	1.615
1500 pop. Density IV	(0.558)	(5.090)
N	1,795,730	1,795,730
16. Contracting institutions	0.009	0.005
	(0.010)	(0.008)
N	1,765,294	1,765,294
17. Contracting institutions:	0.022	0.029**
Legal origins IV	(0.016)	(0.015)
N	1,765,294	1,765,294
18. Both:		
Constraint on the executive	0.075	0.016
	(0.064)	(0.073)
Contracting institutions	0.011	0.006
	(0.008)	(0.007)
N	1,758,649	1,758,649
19. Both: settler mortality and legal origins IV		
Constraint on the executive	-0.439	-0.070
	(0.553)	(0.177)
Contracting institutions	0.125	0.069**
	(0.119)	(0.027)
N	784,723	784,723
20. Both: 1500 pop. density and legal origins IV		
Constraint on the executive	0.824	12.266
	(0.953)	(174.654)
Contracting institutions	0.063	0.430
	(0.054)	(5.229)
N	1,709,131	1,709,131

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Appendix Table 5—Comparative Advantage: Other Measures of Institutions (Continued)

Industries:	All (1)	Clean (2)
21. Both: 1500 pop density, settler mortality, and legal origins IV		
Constraint on the executive	0.000	-0.032
	(0.150)	(0.144)
Contracting institutions	0.055***	0.063***
	(0.020)	(0.022)
N	784,723	784,723

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 log(1+tariffs). Standard errors are clustered by exporter. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 6—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	—	0.000	0.000	0.000	0.000
Energy share	0.002	0.000	0.000	0.001	0.000
Raw materials share	0.000	0.000	0.000	0.001	0.001
Upstreamness	0.000	0.000	0.000	0.001	0.000
Inverse export supply elasticity	0.000	0.000	0.000	0.017	0.000
Mean wage	0.264	0.000	0.000	0.000	0.001
Unemployment (%)	0.078	0.000	0.000	0.000	0.001
College educated	0.001	0.000	0.000	0.001	0.000
Union membership	0.000	0.000	0.000	0.001	0.000
Intra-industry share	0.345	0.000	0.000	0.011	0.000
Geographic dispersion	0.625	0.000	0.000	0.000	0.000
Labor share	0.000	0.000	0.000	0.001	0.000
Capital share	0.502	0.000	0.000	0.000	0.000
Log shipping cost per ton×km	0.000	0.000	0.000	0.139	0.000
Mean firm size	0.021	0.000	0.000	0.000	0.000
Std. dev. Firm size	0.041	0.000	0.000	0.000	0.000
Concentration ratio	0.004	0.000	0.000	0.000	0.000
Log output	0.141	0.000	0.000	0.000	0.000
Output trend 1977-2007	0.128	0.000	0.000	0.001	0.000
All at once	—	0.000	0.035	0.583	0.000

Notes: Each table entry shows the sharpened False Discovery Rate q-value using the method of Anderson (2008), which is a p-value adjusted for multiple hypothesis testing. It can be higher or lower than the p-value from a regression. Table entries and structure correspond to Table 3.

Appendix Table 7—Which Industry Characteristics Explain the Importance of Institutions for Clean Industries? Sequential Analysis

	Association with clean index	Dependence of clean industries on institutions:			Comparative advantage of clean industries
		Financial	Judicial	Labor	
	(1)	(2)	(3)	(4)	(5)
Baseline	—	0.58***	0.49***	0.18***	0.00
	—	(0.05)	(0.04)	(0.05)	0.00
Energy share	-0.37***	0.50***	0.42***	0.16***	0.00
	(0.12)	(0.05)	(0.04)	(0.05)	0.00
Raw materials share	-0.27***	0.44***	0.30***	0.16***	0.00
	(0.04)	(0.05)	(0.04)	(0.05)	0.00
Upstreamness	-0.29***	0.35***	0.18***	0.16***	0.128***
	(0.05)	(0.05)	(0.04)	(0.05)	(0.040)
Inverse export supply elasticity	0.21***	0.38***	0.19***	0.14*	0.072**
	(0.05)	(0.06)	(0.05)	(0.08)	(0.031)
Mean wage	0.15***	0.33***	0.16***	0.09	0.04
	(0.06)	(0.06)	(0.05)	(0.08)	(0.035)
Unemployment (%)	-0.08	0.32***	0.16***	0.07	0.04
	(0.06)	(0.06)	(0.05)	(0.08)	(0.035)
College educated	0.06	0.32***	0.16***	0.08	0.05
	(0.08)	(0.06)	(0.05)	(0.08)	(0.030)
Union membership	-0.20***	0.24***	0.17***	0.05	0.05
	(0.04)	(0.05)	(0.05)	(0.08)	(0.030)
Intra-industry share	0.04	0.24***	0.18***	0.06	0.04
	(0.05)	(0.05)	(0.06)	(0.09)	(0.032)
Geographic dispersion	0.02	0.23***	0.18***	0.07	0.05
	(0.05)	(0.05)	(0.06)	(0.09)	(0.035)
Labor share	0.19**	0.23***	0.14***	0.06	0.05
	(0.08)	(0.05)	(0.05)	(0.09)	(0.035)
Capital share	-0.03	0.23***	0.14***	0.06	0.04
	(0.06)	(0.05)	(0.05)	(0.09)	(0.033)
Log shipping cost per ton×km	-0.22***	0.19***	0.11**	0.05	0.05
	(0.08)	(0.05)	(0.05)	(0.10)	(0.031)
Mean firm size	0.12**	0.19***	0.12**	0.06	0.05
	(0.05)	(0.05)	(0.05)	(0.10)	(0.033)
Std. dev. Firm size	-0.14*	0.19***	0.12**	0.05	0.05
	(0.08)	(0.05)	(0.05)	(0.10)	(0.033)
Concentration ratio	-0.06	0.19***	0.12**	0.05	0.04
	(0.07)	(0.05)	(0.05)	(0.10)	(0.035)
Log output	0.07	0.20***	0.12**	0.06	0.04
	(0.07)	(0.05)	(0.06)	(0.10)	(0.034)
Output trend 1977-2007	0.02	0.19***	0.12**	0.05	0.04
	(0.05)	(0.05)	(0.06)	(0.10)	(0.036)

Notes: Each table entry shows beta coefficients from a separate regression, limited to manufacturing. Each row is sequential, and so includes controls from the previous rows. 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 exporter in column (5). Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 8—Which Industry Characteristics Explain the Importance of Institutions for Clean Industries? Separating Institutions

	Comparative advantage of clean industries		
	Financial	Judicial	Labor
	(1)	(2)	(3)
Baseline	0.051***	0.053***	0.018**
	(0.009)	(0.010)	(0.008)
Energy share	0.046***	0.048***	0.018**
	(0.008)	(0.009)	(0.007)
Raw materials share	0.037***	0.041***	0.018***
	(0.007)	(0.007)	(0.006)
Upstreamness	0.052***	0.061***	0.020**
	(0.009)	(0.010)	(0.008)
Inverse export supply	0.056***	0.064***	0.023***
elasticity	(0.009)	(0.010)	(0.008)
Mean wage	0.048***	0.047***	0.017**
	(0.009)	(0.010)	(0.008)
Unemployment (%)	0.050***	0.051***	0.017**
	(0.009)	(0.010)	(0.008)
College educated	0.044***	0.042***	0.014**
	(0.008)	(0.009)	(0.007)
Union membership	0.046***	0.056***	0.015**
	(0.008)	(0.008)	(0.007)
Intra-industry share	0.057***	0.063***	0.021**
	(0.010)	(0.011)	(0.008)
Geographic dispersion	0.051***	0.054***	0.018**
	(0.009)	(0.010)	(0.008)
Labor share	0.050***	0.063***	0.022***
	(0.009)	(0.009)	(0.008)
Capital share	0.051***	0.053***	0.019**
	(0.009)	(0.010)	(0.008)
Log shipping cost per	0.042***	0.041***	0.011*
ton×km	(0.007)	(0.010)	(0.006)
Mean firm size	0.050***	0.053***	0.018**
	(0.009)	(0.009)	(0.008)
Std. dev. Firm size	0.049***	0.053***	0.018**
	(0.009)	(0.009)	(0.008)
Concentration ratio	0.049***	0.052***	0.019**
	(0.009)	(0.009)	(0.008)
Log output	0.052***	0.059***	0.019**
	(0.009)	(0.009)	(0.008)
Output trend 1977-2007	0.050***	0.051***	0.017**
	(0.009)	(0.010)	(0.008)
All at once	0.025***	0.037***	0.013***
	(0.005)	(0.005)	(0.004)

Notes: Each table entry shows beta coefficients from a separate regression, limited to manufacturing. Table entries estimate equation (4), but also controlling for the interaction of institutions with the variable indicated in each row. Parentheses show robust standard errors clustered by exporter. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 9—Correlation of Composition and Institutions

Composition-pollutant	(1) All	(2) CO	(3) NMVOC	(4) NO_x	(5) $PM_{2.5}$	(6) SO_x
Panel A: Financial institutions						
Institutions	-2.92**	-2.44***	-6.74*	-2.91**	-0.08	-2.43**
	(1.32)	(0.90)	(3.46)	(1.27)	(0.22)	(1.18)
Panel B: Judicial institutions						
Institutions	-3.32***	-3.11***	-7.23**	-3.32***	-0.39**	-2.54**
	(1.07)	(0.70)	(2.93)	(1.00)	(0.16)	(1.04)
Panel C: Labor market institutions						
Institutions	1.20	0.76	3.26	1.11	-0.09	0.96
	(1.52)	(0.96)	(4.02)	(1.45)	(0.19)	(1.24)
Panel D: All institutions at once						
Financial institutions	-0.43	0.25	-1.78	-0.39	0.50	-0.70
	(1.25)	(1.19)	(3.12)	(1.22)	(0.37)	(1.17)
Judicial institutions	-3.63***	-3.60***	-7.67***	-3.62***	-0.63**	-2.62**
	(1.02)	(0.93)	(2.79)	(0.94)	(0.24)	(1.14)
Labor market institutions	2.22	1.63*	5.60	2.12	-0.03	1.78
	(1.44)	(0.83)	(3.87)	(1.36)	(0.19)	(1.22)
Panel E: Institutions index						
Institutions	-1.79	-1.72**	-3.79	-1.81	-0.23*	-1.40
	(1.18)	(0.70)	(3.19)	(1.12)	(0.12)	(1.00)

Notes: each regression has composition as the dependent variable. All regressions include N=46, each observation represents one country. Composition is the unweighted mean for a focal country across all reference countries. CO is carbon monoxide, NMVOC 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. Robust standard errors shown in parentheses. Asterisks denote p-value * < 0.10, ** < 0.05, *** < 0.01.

Appendix Table 10—Effects of Counterfactual Institutions, by Pollutant: Model-Based Analysis

Change in …	CO (1)	NMVOC (2)	NO_x (3)	$PM_{2.5}$ (4)	SO_x (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%*

(Continued next page)

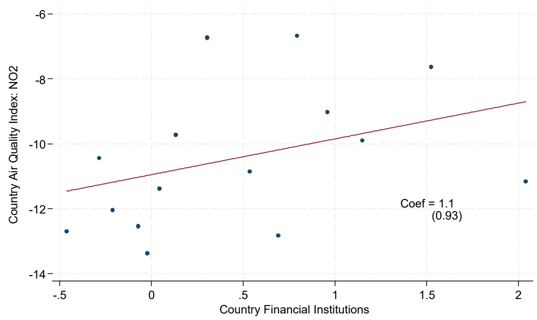
Appendix Table 10—Effects of Counterfactual Institutions, by Pollutant: Model-Based Analysis (Continued)

Change in …	CO	NMVOC	NO_x	$PM_{2.5}$	SO_x
	(1)	(2)	(3)	(4)	(5)
Panel D. Counterfactual: improve institutions in all countries equally					
Pacific Ocean	-0.1%	0.7%	1.4%	1.0%	0.9%
Western Europe	1.7%	-0.5%	2.4%	0.4%	0.2%
Eastern Europe	0.4%	-0.5%	-1.0%	-0.2%	-0.7%
Latin America	-4.2%	-1.4%	-1.5%	-3.2%	-3.2%
North America	2.1%	0.6%	1.6%	1.8%	1.3%
China	-3.0%	-1.6%	-1.5%	-2.1%	-2.0%
Southern Europe	1.1%	-0.1%	0.4%	0.2%	0.3%
Northern Europe	1.0%	-0.3%	0.4%	0.1%	-0.1%
Indian Ocean	-2.0%	-0.9%	-0.4%	-1.6%	-1.9%
Rest of World	-2.5%	-0.5%	-1.0%	-2.2%	-1.9%
Global	-1.6%	-0.6%	-0.1%	-1.6%	-1.4%
Panel E. Add 1996-2015 changes in institutions					
Pacific Ocean	2.8%	0.7%	0.4%	1.1%	1.4%
Western Europe	2.0%	0.7%	0.5%	1.1%	1.1%
Eastern Europe	-1.4%	-0.9%	-0.9%	-1.2%	-0.9%
Latin America	-0.1%	-0.1%	-0.2%	0.0%	-0.2%
North America	1.1%	0.6%	0.5%	1.0%	0.6%
China	-4.0%	-2.2%	-2.0%	-3.2%	-2.7%
Southern Europe	2.4%	0.9%	0.4%	1.2%	0.9%
Northern Europe	-4.7%	-2.3%	-1.2%	-2.9%	-2.5%
Indian Ocean	2.6%	1.0%	0.4%	1.8%	1.8%
Rest of World	1.0%	0.3%	0.4%	1.0%	0.8%
Global	-0.8%	-0.4%	-0.1%	-0.8%	-0.5%

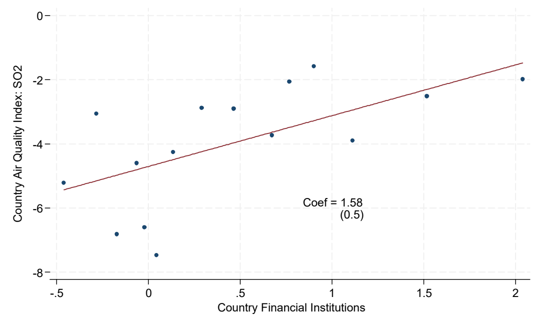
Notes: Table structure and entries are analogous to Table 4. This table shows percentage change in each air pollutant in Exiobiase, whereas Table 4 shows change in index of pollutants. CO is carbon monoxide, NMVOCs is non-methane volatile organic compounds, NO_x is nitrogen oxides, $PM_{2.5}$ is particulate matter smaller than 2.5 micrometers, and SO_x is sulfur oxides.

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

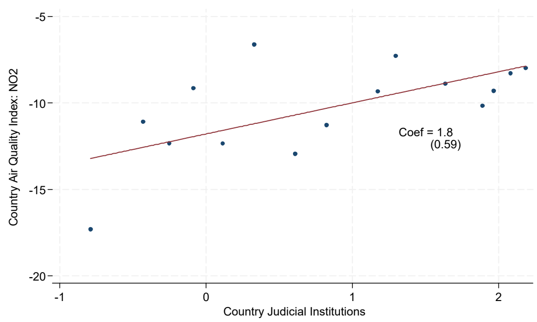
(A) Country NO_2 & financial institutions



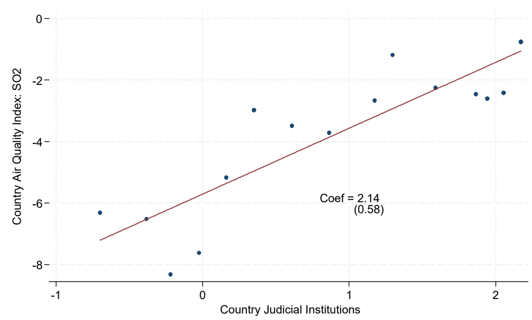
(B) Country SO_2 & financial institutions



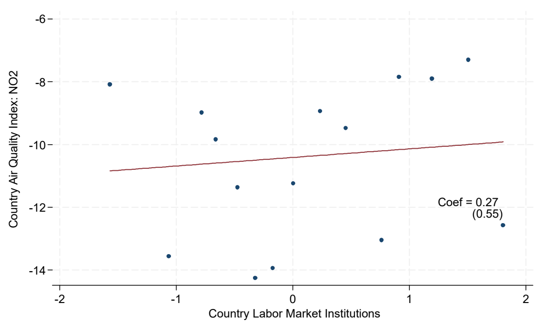
(C) Country NO_2 & judicial institutions



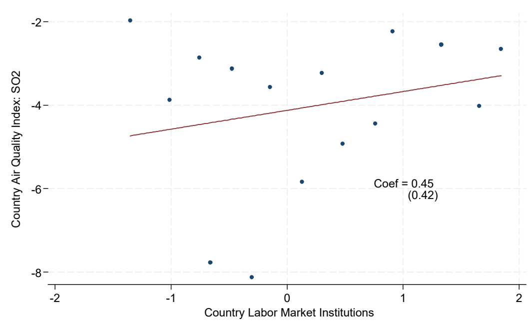
(D) Country SO_2 & judicial institutions



(E) Country NO_2 & labor market institutions



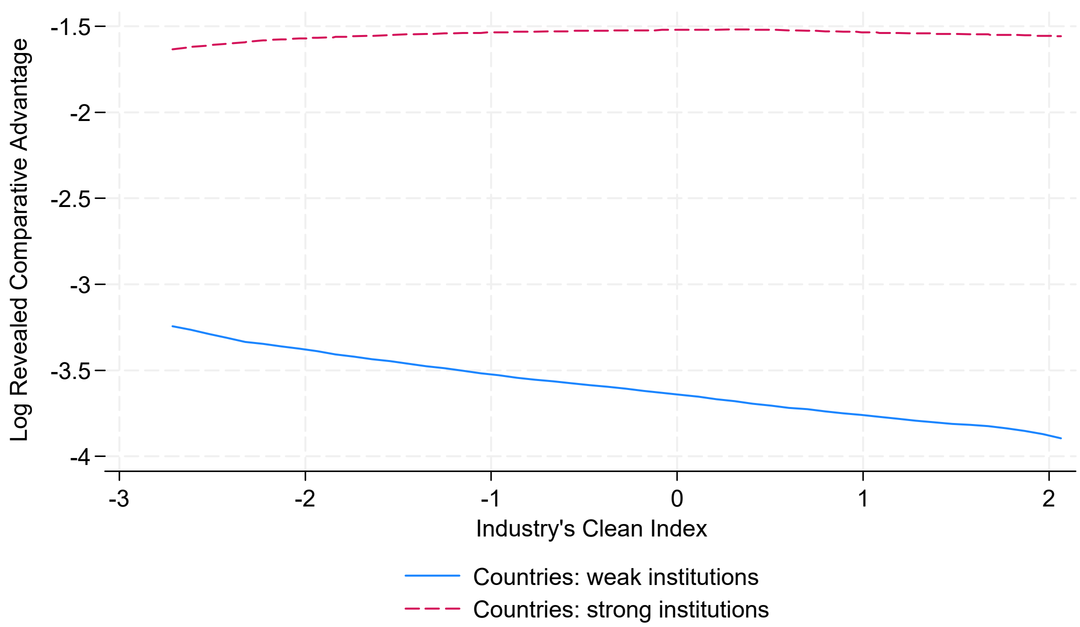
(F) Country SO_2 & labor market institutions



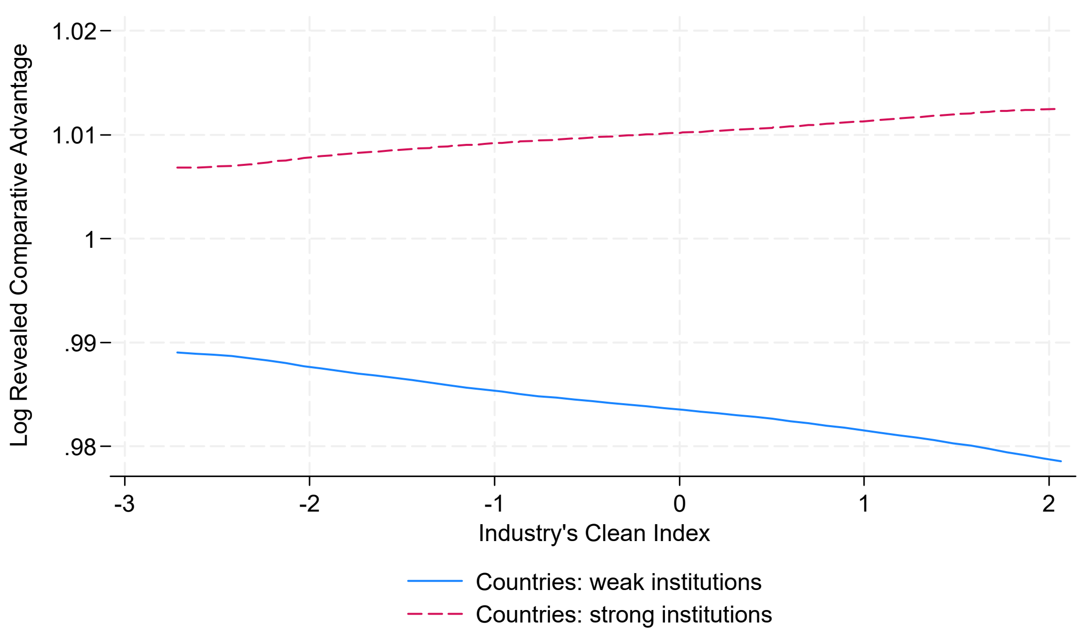
Notes: Graphs show binned scatter plots. Each observation in the underlying data represents a country. Within a country, air pollution data are averaged over available cities and years. Air quality equals minus one times the air quality index for the relevant pollutant. Blue circles are means of 15 evenly-sized 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)

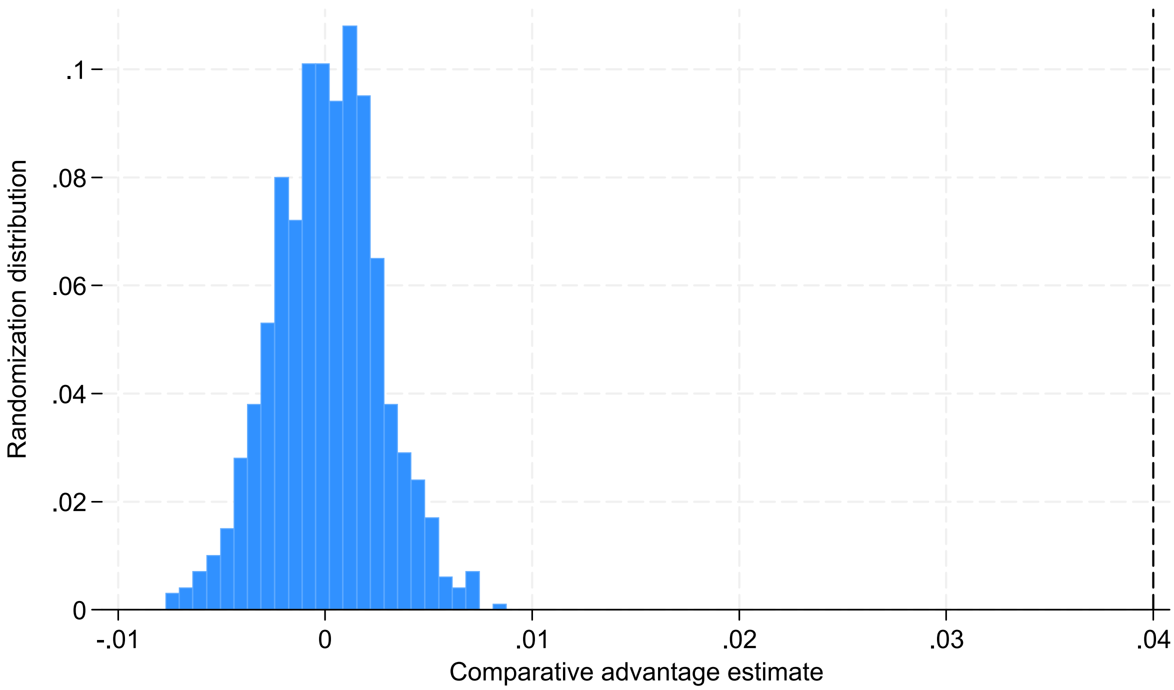


(B) Index of Costinot, Donaldson, and Komunjer (2012)



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.

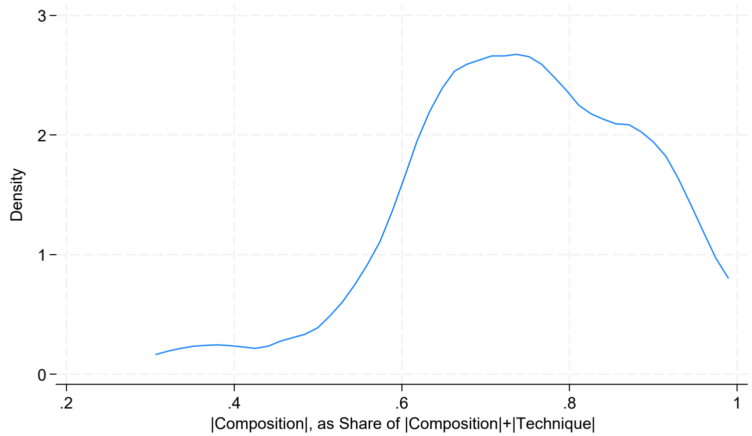
Appendix Figure 3: Randomization Inference



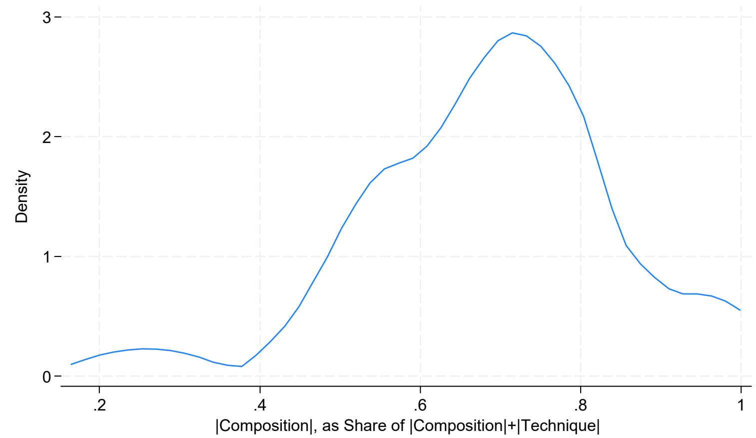
Notes: graph shows the empirical distribution of the coefficient on country institutions × clean industry from equation (9). The empirical distribution comes from 1,000 samples of the data, where each estimate randomly reshuffles institutions across countries and randomly reshuffles the clean index across industries. The vertical red line shows the full-sample estimate without reshuffling, from Table 2, Panel B, column (10).

Appendix Figure 4. Importance of Composition Versus Technique, by Reference Country

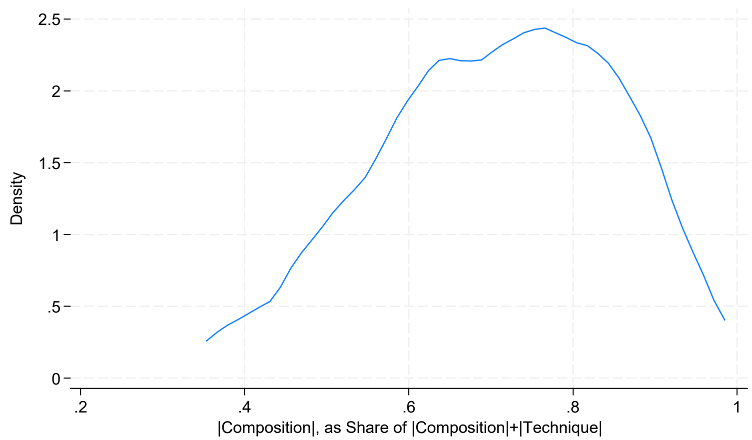
Panel A. Reference Country: China



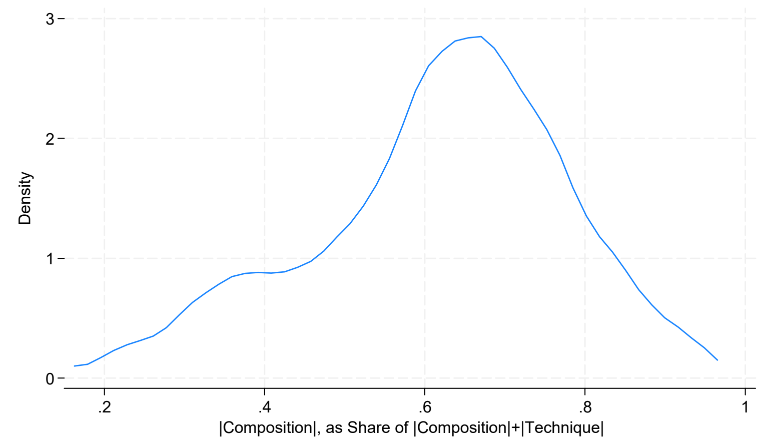
Panel B. Reference Country: Germany



Panel C. Reference Country: India



Panel D. Reference Country: US



Notes: the graphs plot the distribution across all possible comparison countries and averaged over each local pollutants. For each country *r*, the analysis calculates |*composition*| averaged across all country pairs while using the indicated country as focal or reference, divided by |*composition*|+|*technique*| . Each underlying point averages across (r,i) and (i,r) country pairs (e.g., US-China and China-US), and across air pollutants in Exiobase. Pollution emission rates are winsorized at the 99.9th percentile and calculation excludes industry*year cells with less than $10,000 in annual sales.

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