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Environmental Regulation, Environmental Intensity, and Trade

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Abstract: The impact of environmental regulation on trade depends on the competitive forces between compliance costs (à la pollution haven hypothesis) and technology improvement (à la Porter hypothesis). This paper develops a Ricardian model that accounts for two-sector production. Trade shares and prices rely on the aggregate effects of technological progress and compliance costs. Country-level environmental regulation stringency affects trade shares and prices across industries that differ in environmental intensity. Using bilateral trade data and instrumenting a country's environmental regulation stringency with temperature anomalies, we empirically confirm the theoretical implications on the basis in which the Porter hypothesis plays a more dominant role.

Keywords: Environmental Regulation, Environmental Intensity, Trade, Porter Hypothesis, Technological Progress

JEL Classifications: F14, F18, Q58

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1. Introduction

Much attention has been attached to the environment due to serious environmental issues worldwide, such as global warming, air pollution, and forest degradation. Various types of environmental regulation are proposed and enacted in many countries for sustainable development.[1] There has been much debate about the impact of environmental regulation on the competitiveness of affected economic entities. Two opposing views in the literature on this effect are held, the pollution haven hypothesis and the Porter hypothesis.

The pollution haven hypothesis believes that stringent environmental policy increases compliance costs.[2] Thus, shift pollution-intensive production toward low abatement cost regions, creating pollution havens and causing policy-induced pollution leakage (e.g., Levinson and Taylor, 2008).[3] Some empirical work supports this hypothesis by showing that stringent environmental policy adversely affects competitiveness, accounting for unobserved heterogeneity and endogeneity though (e.g., Brunnermeier and Levinson, 2004; Copeland and Taylor, 2004). In that case, industries producing environmental goods will lose comparative advantages in the countries with stricter environmental regulation due to the compliance costs. Thus, these countries are supposed to increase imports and reduce exports of environmental goods. However, most empirical work finds either a zero or a positive effect of more stringent environmental regulation on net exports (e.g., Jaffe et al., 1995; Xu, 1999).

This puzzle is explained by the Porter hypothesis, which argues that the economic system is not static where environmental policy only lays a burden on regulated firms. Instead, stringent environmental policies can exert a net positive effect on the competitiveness of regulated firms since such policy is able to promote cost-cutting efficiency improvement, which in turn offsets or exceeds the regulatory costs (e.g., Porter and van der Linde, 1995; Mohr, 2002). Some studies back up the effects of technological progress by showing that

[1] The first major environmental regulation, the Stockholm Declaration and Action Plan for the Human Environment, which tightened the links between economic growth, environment and well-beings of people, highlighted the international aspects of emerging environmental challenges and environmental management actions by the United Nations Conference on the Human Environment in 1972.

[2] Pasurka (2008) documents that the share of manufacturing capital expenditure assigned to pollution abatement in 2000 ranged from 1% in Taiwan to 5% in Canada.

[3] Precedents find that lax environmental regulation in a host country is a significant determinant of foreign direct investment (e.g., Keller and Levinson, 2002; Chung, 2014; Xing and Kolstad, 2002), while some studies find no systematic evidence to support pollution haven hypothesis (e.g., Javorcik and Wei, 2003; Eskeland and Harrison, 2003). In addition, Dong et al. (2012) find that FDI is likely to raise the emission standard of the host country.

stricter environmental regulation leads to higher R&D expenditures and more environment-related patents (e.g., Jaffe and Palmer, 1997; Brunnermeier and Cohen, 2003; Aghion et al., 2016). Additionally, a bunch of papers document that in many high-income countries, environmental regulation reduces pollution due to the technique effects (Levinson, 2009, 2015; Cherniwchan et al., 2017; Cherniwchan and Taylor, 2022).

It can be inferred that the impact of environmental regulation on competitiveness depends on the competing force between the pollution haven hypothesis and the Porter hypothesis. Several papers summarize key stylized facts on environmental benefits and compliance costs, and show that much of the environmental regulation has benefits that exceed costs. Shapiro and Walker (2020) find that marginal benefits of environmental regulation exceed offset prices by more than ten-fold on average. A recent review finds that between 1992 and 2017, the ratio of total estimated benefits to total estimated costs was 12.4 for air pollution, 4.8 for water, and 3.0 for greenhouse gases (Keiser and Shapiro, 2019).[4] Firms adopting a cooperative and proactive stance on environmental protection generally view environmental protection as an opportunity to improve the operation performance though complying with mandated responsibility, such as 3M, and Dupont (Porter and van der Linde, 1995).[5]

Based on the above theoretical hypotheses, environment regulation could be assessed as a potential source of comparative advantage in international trade (Copeland and Taylor, 1994, 1995; Ederington et al., 2005; Levinson and Taylor, 2008), but the direction is ambiguous. This paper investigates how environmental regulation affects trade across countries and industries relying on environmental resources.

[4] For example, a voluntary program, Green Lights, was launched by the U.S. Environmental Protection Agency (EPA) in 1991. Firms participating in this program must survey all of their facilities and electrical energy consumption, and upgrade the lighting systems. In return, they are offered information advice and energy-efficient lighting technology. As shown in an EPA report on the Green Lights program, nearly 80% of the projects had paybacks of two years or less (DeCanio, 1993).

[5] For example, 3M discovered that one bad batch could spoil the entire contents of a storage tank in producing adhesives, generating hazardous wastes and costs of waste disposal. 3M developed a new technique to run quality tests more rapidly on new batches, which reduced waste and yielded considerable savings. Another example is that China lays out specific targets and measures for reaching peak carbon emissions by 2030 and carbon neutrality by 2060. The primary targets are designed to reduce emissions and pollution, likely imposing additional costs on businesses. However, the fundamental goal is to eliminate backward and inefficient production capacity, promote technological development and application, and achieve industrial upgrading. Accordingly, the Chinese firms that pay extra costs for emission reduction through purchasing abatement facilities and developing abatement technology indeed realize technology upgrading, thus gaining greater benefits.

We start by proposing a simple two-sector model to study the response of different types of production to environmental regulation, which can either decrease the production costs of environmental goods because of technological progress or increase the production costs of environmental goods because of compliance costs. The production of final goods is determined by combining environmental goods and non-environmental goods from two sectors. Following Eaton and Kortum (2002), we then embed the production with environmental regulation into a Ricardian model. Utilizing the Fréchet distribution and gravity equation, we show how the competitive force of environmental regulation affects trade shares and trade prices in countries with different stringency of environmental regulation and industries with different environmental intensity. In particular, if the effects of the Porter hypothesis (i.e., technological progress) dominate the effects of the pollution haven hypothesis (i.e., compliance costs), a country with more stringent environmental regulation gains comparative advantages in environment, and thus exports relatively more in environment-intensive industries, while imports relatively less and at a lower price. Conversely, if the effects of the pollution haven hypothesis are greater than the effects of the Porter hypothesis, the opposite results obtain.

We then conduct the empirical analysis to test the theoretical propositions. Following Kellenberg (2009), we measure countries' environmental regulation stringency from survey data. Moreover, propose a methodology to calculate industries' environmental intensity with the list of environmental goods and Input-Output (I-O) table. To address the potential endogenous issue, we calculate the temperature anomalies that reflect the volatility of historical temperature of each country between 1950 and 1990, and instrument for each country's environmental regulation stringency. The empirical specification in this paper is closely referred to the one employed in Cui et al. (2022), which mitigates potential omitted variable bias by controlling for demand-side or supply-side confounding factors. Using the United Nations (UN) Comtrade data, we obtain the paired trade data in different countries and industries, thus investigating the effects of cross-country differences in environmental regulation on trade shares and trade prices across industries with different environmental intensity. Our empirical results suggest that in the real world with a multi-country environment, the effects of the Porter hypothesis dominate the effects of the pollution haven hypothesis: Stringent environmental regulation promotes trade.[6] In addition, the visualization of quasi-Rybczynki effects shows that export shares of economies with the fastest-growing environmental regulation stringency have shifted toward environment-intensive industries in the long run.

This paper contributes to the literature on three grounds. We mainly investigate the impacts of environmental regulation on trade shares and prices, rather than the adverse effects of trade on environment documented in the literature (e.g., Copeland and Taylor, 1994, 1995; Antweiler et al., 2001; Frankel and Rose, 2005; Shapiro, 2016; Cherniwchan, 2017). Our framework fills gaps in the literature by illustrating how environmental regulation shapes comparative advantages in environment and further affects trade in a multi-country environment.[7] Our research complements the findings that high-income countries choose stronger environmental policies and specialize in producing environmental goods (Copeland and Taylor, 1994). In addition, we seek to study variations in trade considering the role of environmental regulation, which is devoted to the literature studying this topic concerning other institutional factors, such as trade policy (Trefler, 2004; Ossa, 2014; Handley and Limão, 2017), contracting quality (Levchenko, 2007; Cui et al., 2022), intellectual property rights protection (Maskus and Penubarti, 1995), financial policy (Bacchetta and Van Wincoop, 2000; Meissner, 2003; Manova, 2013).

We highlight the role of environmental regulation by nesting both the Porter hypothesis and pollution haven hypothesis, contributing to a strand of literature discussing the pollution haven effects brought by environmental regulation. A recent review concludes that although pollution haven effects are well documented, there are no credible estimates understanding if it is larger or smaller than other factors (Cherniwchan and Taylor, 2022). This paper is linked to the literature on the impacts of environment on technical change (Acemoglu et al., 2012;

[6] Consistent with the theoretical prediction, empirical evidence shows that, on the one hand, environmental regulation increases comparative advantages in environment, and further affects trade shares and prices. Specifically, an exporter with stricter environmental regulation exports relatively more in environment-intensive industries due to stronger comparative advantages in environment, while environmental regulation does not have explicit impacts on the price since the export price is determined by the global price index. On the other hand, an importer with stricter environmental regulation has stronger comparative advantages in environment, and thus it imports relatively less in environment-intensive industries, and imports at a lower price because only products at a lower price can be imported.

[7] Grossman and Krueger (1991) study the effects of environmental regulation induced by the North American Free Trade Agreement on trade between the U.S. and Mexico, but find little evidence due to identification issues.

Aghion et al., 2016; Calel and Dechezleprêtre, 2016), and innovation (Porter and van der Linde, 1995; Jaffe and Palmer, 1997; Nesta et al., 2014).[8] Moreover, Acemoglu et al. (2014) investigate the relationship between environment and technical change using a North-South model, focusing on technology diffusion and coordination of global environmental policy.[9] Our analysis adds to this study by modeling these factors into a Ricardian model, and showing different mechanisms of environmental regulation on trade.

This paper provides new evidence for the impacts of environmental regulation on trade following the empirical approach employed by Cui et al. (2022). Moreover, we propose a method to calculate industry-level environmental intensity to measure the industry's dependency on environment by combining the list of environmental goods from the Organization for Economic Co-operation and Development (OECD) and the Input-Output table. Using the weather data to construct an instrumental variable (IV), temperature anomalies, for a country's environmental regulation stringency. Therefore, we are able to test our theory at the country-industry level empirically, enriching the extant literature related to this topic.[10]

The rest of the paper is organized as follows. Section 2 introduces the theoretical framework and propositions. Section 3 presents the identification strategy. Section 4 describes data and variables. Section 5 reports the empirical results of baseline model. Section 6 conducts robustness checks, considers heterogenous effects, and visualizes the dynamic effects. Section 7 concludes.

2. Model

We consider an open economy with trade in final goods whose production is impacted by the role of environmental regulation. The competition force of environmental regulation (i.e.,

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[8] This paper also expands the research scope on environmental regulation. For example, the literature studies the effects of environmental regulation on pollution reduction (Henderson, 1996; Greenstone and Hanna, 2014), on economic development (Dasgupta et al., 2001; Jalilian et al., 2007), on productivity (Barbera and McConnell, 1990; Boyd and McClelland, 1999; Berman and Bui, 2001; Albrizio et al., 2017).

[9] As well documented, technology is a determinant of trade (Grossman and Helpman, 1995; Eaton and Kortum, 2002; Levinson, 2009).

[10] When considering the environment, previous research focuses more on either country-level analysis (e.g., Jaffe and Palmer, 1997; Kellenberg, 2009), or industry-level analysis (e.g., Levinson, 2009; Shapiro and Walker, 2018).

technological progress versus compliance costs) affects production, and thus trade shares, and trade prices across countries and industries.

2.1. Demand

We assume that all representative consumers in each country follow the constant elasticity of substitution (CES) preferences over a continuum of varieties $\omega \in [0,1]$,

$$U = \left\{ \int_0^1 Q(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right\}^{\frac{\sigma}{\sigma-1}}$$

where $\sigma > 1$ is the elasticity of substitution between varieties, $Q(\omega)$ is the total consumption.

The budget constraint is

$$X \geq \int_0^1 P(\omega) \cdot Q(\omega) d\omega$$

where $P(\omega)$ is the price of goods, X is the total expenditure.

Demand for the consumption of variety ω, is

$$Q(\omega) = P(\omega)^{-\sigma} \cdot \Psi^{\sigma-1} \cdot X \tag{1}$$

where Ψ is the exact price index, and $\Psi = \left(\int_0^1 P(\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}$.

2.2. Production

Final goods are produced competitively using environmental inputs, and non-environmental inputs. A final goods producer buys environmental (e) and non-environmental (n) goods from suppliers.[11] Production of final goods depends on the input bundle, which is

$$Q(\omega) = \varphi(\omega) \cdot Q_e(\omega)^{\eta} \cdot Q_n(\omega)^{1-\eta} \tag{2}$$

[11] Environmental goods can be either clean products (e.g., water filtering machines, gas purifying machines) or dirty products (e.g., gas generators, primary batteries, articles of exhaustible resources). Producers of these two types of products possibly both upgrade their technology and loss because of compliance costs under environmental regulation. The classification of specific environmental goods for empirical analysis will be introduced in Section 4.

where $\varphi(\omega)$ is the production efficiency. $Q_e(\omega)$ and $Q_n(\omega)$ are requirements of environmental goods and non-environmental goods. η is the elasticity of input bundle with respect to environmental input, measuring the importance of environmental input. Production is subject to $p_e \cdot Q_e + p_n \cdot Q_n = X$. As the final goods are produced competitively, the relative price of the two inputs satisfies

$$\frac{p_e}{p_n} = \frac{\eta}{1-\eta} \cdot \left(\frac{Q_e}{Q_n} \right)^{-1} \tag{3}$$

Following prior research studying technological progress by environmental regulation (e.g., Acemoglu et al., 2012; Acemoglu et al., 2014), we set that the environmental goods and non-environmental goods are produced using labor and a continuum of sector-specific machines (intermediates), as

$$Q_e = \left[(1+\delta)^{\gamma} \cdot x_e^{\ \alpha} \right] \cdot L_e^{1-\alpha}$$

$$Q_n = x_n^{\ \alpha} \cdot L_n^{1-\alpha}$$

where x_e and x_n are specific machines in each sector. δ is the stringency of environmental regulation of a country, $0 < \delta < 1$. Here, it captures the effects of the Porter hypothesis that stricter environmental regulation catalyzes technology advancement, and thus increases production efficiency, which we call "technique effects" in this paper. And $0 < \gamma < 1$, suggests that technical upgrading is subject to diminishing return.

Market clearing for labor requires labor demand to be less than total labor supply, which is normalized to 1, as

$$L_e + L_n \le 1 \tag{4}$$

The costs of producing a machine in the environmental sector is $(1+\delta)^{\mu} \cdot \kappa$, in the non-environmental sector is κ.[12] The production costs of specific machines are higher in the

[12] Following Acemoglu et al. (2012), machines in two sectors are both supplied by monopolistically competitive firms. Producing one unit of machines costs κ units of the final good in the non-environmental sector, while costs $(1+\delta)^{\mu} \cdot \kappa$ units of the final good in the environmental sector. Different from their work, we do not set a specific form for κ.

environmental sector according to the stringency of environmental regulation, δ.[13] That is, producers that produce environmental goods need to pay compliance costs through purchasing more expensive machines to comply with the regulation, which captures the effects of pollution haven hypothesis. There are "substitution effects", the environmental input becomes relatively more expensive, which reduces the demand for the environmental input, and therefore its production. Thus, we obtain the relative price of the two inputs, as

$$\frac{p_e}{p_n} = \left(\frac{1}{1+\delta}\right)^{\gamma-\alpha\mu} \tag{5}$$

which implies that the relative price of environmental input to non-environmental input is determined by the aggregate effects of environmental regulation. And the relative employment is

$$\frac{L_e}{L_n} = \frac{\eta}{1-\eta} \tag{6}$$

Finally, we can obtain the average cost of producing the final goods, as[14]

$$C(\omega) = \lambda \cdot (1+\delta)^{-\eta(\gamma-\alpha\mu)} \cdot \varphi(\omega)^{-1} \tag{7}$$

where $\lambda \equiv \alpha^{-2\alpha} \cdot (1-\alpha)^{\alpha-1} \cdot \kappa^{\alpha} \cdot \eta^{-\eta} \cdot (1-\eta)^{-(1-\eta)} \cdot w^{1-\alpha}$. The costs of producing final goods depend on the aggregate effects of environmental regulation between the strength of technique effects, γ, and that of substitution effects, $\alpha\mu$. If $\gamma > \alpha\mu$, the technique effects dominate, thus stricter environmental regulation strengthens comparative advantages in environment, reducing the production costs of final goods. Otherwise, if $\gamma < \alpha\mu$, the substitution effects dominate, thus stricter environmental regulation weakens comparative advantages in environment, increasing the production costs of final goods.

2.3. Trade Shares and Trade Prices

[13] We introduce compliance costs of environmental regulation into the model in this form to obtain the analytical solution simply. Environment regulation imposes additional costs for producing environmental goods, such as environmental taxes and installation of emission reduction equipment, which is ultimately embodied in higher costs of intermediate goods. As long as the costs are an increasing function of environmental regulation stringency δ, the theoretical predictions always hold.

[14] See Appendix A.1 for the proof.

Following Cui et al. (2022), we embed the above production process into a Ricardian model by Eaton and Kortum (2002). For each variety of final goods, there is perfect competition among producers from different countries. Producers produce variety ω at the same cost in the same country. Trading final goods from exporter (o) to importer (d) entails an *ad valorem* cost τ_{do}. Thus, the price per unit of final goods ω sold from o to d is

$$P_{do}(\omega) = \tau_{do} C_o(\omega) = \tau_{do} \cdot \lambda_o \cdot \left(1+\delta_o\right)^{-\eta(\gamma-\alpha\mu)} \cdot \varphi_o(\omega)^{-1}$$

Following Eaton and Kortum (2002), we assume that the production efficiency of the exporter o, $\varphi_o(\omega)$ is drawn from a Fréchet distribution, as

$$\Pr\left[\varphi_o(\omega) \leq \varphi\right] = G_o(\varphi) = \exp\left(-T_o \cdot \varphi^{-\theta}\right) \tag{8}$$

where T_o governs the location of the distribution, and θ is the dispersion parameter.

Consumer's utility in the importing country d depends on effective consumption $Q_d\left(\omega\right)$, and the relevant price for consumer's decision is $P_{do}\left(\omega\right)$. Under perfect competition, consumers in the importing country d purchase each variety ω of final goods from the exporting country o that provides the lowest $P_{do}\left(\omega\right)$, which is $P_d(\omega) = \min_o\left\{P_{do}(\omega); \forall o\right\}$. Thus, the probability that the exporter o offers a good at the lowest price can be characterized, as

LEMMA 1. *When $\varphi_o(\omega)$ follows the Fréchet distribution, the probability that importer d buys a particular variety ω from exporter o, π_{do}, is*

$$\pi_{do} = \frac{T_o \cdot \tau_{do}^{-\theta} \cdot \lambda_o^{-\theta} \cdot \left(1+\delta_o\right)^{\theta\eta(\gamma-\alpha\mu)}}{\Phi_d} \tag{9}$$

where $\Phi_d = \sum_s T_s \cdot \tau_{ds}^{-\theta} \cdot \lambda_s^{-\theta} \cdot \left(1+\delta_s\right)^{\theta\eta(\gamma-\alpha\mu)}$, which is a price parameter around the world summarizing the characteristics, including states of technology, trade barriers, input costs, input structures, environmental regulation, and environmental intensity.[15]

This gravity equation implies that the environmental regulation affects bilateral trade probability and fraction, which depends on the aggregate effects between the technique effects and substitution effects, together with environmental intensity. In particular,

[15] See Appendix A.2 (I) for the proof of Lemma 1.

environmental regulation matters more for the bilateral trade in environment-intensive industries (i.e., high-η industries).

Because importing country d buys from the least cost provider, the probability distribution of $P_d(\omega)$ is

$$G_d(P) = 1 - \exp\left(-P^{\theta} \cdot \Phi_d\right) \tag{10}$$

which is also the effective price distribution of varieties that d actually buys from o, $\tilde{G}_{do}(P)$.[16] And the exact price index in country d is calculated straightforwardly, as

$$\Psi_d = \Phi_d^{-\frac{1}{\theta}} \cdot \Gamma\left(1 + \frac{1-\sigma}{\theta}\right)^{\frac{1}{1-\sigma}} \tag{11}$$

where Γ is the Gamma function. It shows that the price index Ψ_d is inversely related to Φ_d. Thus, one country's environmental regulation stringency affects all countries with the global price index. And an importing country that has better access to the global market with high-Φ_d gets a lower price index.[17]

Because $\tilde{G}_{do}(P) = G_d(P)$ holds for exporters given importer d, the value of bilateral trade flows from o to d is proportional to the sourcing probability π_{do}, which is $X_{do} = \pi_{do} \cdot X_d$. Thus, the bilateral trade price from o to d can be defined as

LEMMA 2. *The price of trade from o to d is*

$$P_{do} \equiv \left[P_{do}(\omega) \mid \omega \in \Omega_{do}\right] = \Phi_d^{-\frac{1}{\theta}} \cdot \Gamma\left(1 + \frac{1}{\theta}\right) \propto \Psi_d \tag{12}$$

where Ω_{do} is the set of varieties that d actually buys from o.[18] Lemma 2 shows that the aggregate trade price P_{do} has no bearing on environmental regulation in country o. Besides,

[16] We obtain this result by calculating $\tilde{G}_{do}(P) = \Pr\left[P_{do}(\omega) \le P \middle| P_{do}(\omega) \le P_{ds}(\omega); \forall s \ne o\right]$. Intuitively, the price distribution of goods that d buys from o is equal to the price distribution of all goods consumed in d, suggesting a non-arbitrage condition under perfect competition. Otherwise, country d will increase imports from other exporters offering lower prices until there are no differences in the price among exporters.

[17] A high Φ_d indicates a more competitive market in importing country d.

[18] See Appendix A.2 (II) for the proof of Lemma 2.

trade price P_{do} is decreasing in Φ_d since only goods with lower prices are tradable in the global market with high-Φ_d.

2.4. Trade Margins

We are now in a position to examine the effects of cross-country differences in environmental regulation stringency on trade margins across industries with different environmental intensity. We first consider whether a specific country's environmental regulation impacts global competition toward other countries through trade, which can be explored as

$$\frac{\partial \ln \Phi_d}{\partial \ln(1+\delta_o)} = \theta\eta(\gamma - \alpha\mu) \cdot \pi_{do}$$

Environmental regulation in o affects competition around the world. In particular, if $\gamma > \alpha\mu$, stricter environmental regulation increases competition with environmental intensity η and the bilateral trade share between o and d. Specifically, if o is a major exporter of d, a change in environmental regulation in country o, δ_o, would yield large effects on the competitive environment in d. On the contrary, if $\gamma < \alpha\mu$, global competition decreases with stronger environmental regulation incorporating environmental intensity and market share of o in d.

Next, we study how environmental regulation in an exporting country or importing country affects bilateral trade. Note that when examining the effects of environmental regulation on export, the comparison of exporters with different δ_o is conditional on the same importer to eliminate demand-specific confronting factors, which is denoted as $|_d$. Similarly, we compare importers with different δ_d conditional on the same exporter as $|_o$.

The effects of environmental regulation on trade shares can be derived from the bilateral trade probability with respect to environmental regulation stringency, δ_o or δ_d, and environmental intensity, η. Thus, we obtain the following propositions.

PROPOSITION 1. *Conditional on an importer d: If $\gamma > \alpha\mu$, the technique effects dominate the substitution effects, then a country with more stringent environmental regulation exports relatively more to d in environment-intensive industries. If $\gamma < \alpha\mu$, the substitution effects* *dominate the technique effects, then a country with more stringent environmental regulation exports relatively less to* d *in environment-intensive industries.*[19]

$$\left.\frac{\partial^2 \ln \pi_{do}}{\partial \ln(1+\delta_o)\partial \eta}\right|_d = \theta(\gamma - \alpha\mu) \tag{13}$$

which indicates that how an exporter's environmental regulation impacts on export shares in industries with different environmental intensity taking both the technique effects and substitution effects into account. In particular, if $\gamma > \alpha\mu$, the technique effects dominate the substitution effects, Equation (13) is greater than 0. That is, more stringent environmental regulation of an exporting country increases the country's exports to d in high-η industries. It implies a Heckscher-Ohlin effect in terms of environment. On the contrary, if $\gamma < \alpha\mu$, the substitution effects dominate the technique effects, Equation (13) is smaller than 0. In that case, a country with more stringent environmental regulation decreases export shares to d in high-η industries.

PROPOSITION 2. *Conditional on an exporter* o*: If* $\gamma > \alpha\mu$*, the technique effects dominate the substitution effects, then a country with more stringent environmental regulation imports relatively less from* o *in environment-intensive industries. If* $\gamma < \alpha\mu$*, the substitution effects dominate the technique effects, then a country with more stringent environmental regulation imports relatively more from* o *in environment-intensive industries.*[20]

$$\left.\frac{\partial^2 \ln \pi_{do}}{\partial \ln(1+\delta_d)\partial \eta}\right|_o = -\theta(\gamma - \alpha\mu)\cdot \pi_{dd} \cdot \left(1 + \frac{\partial \ln \pi_{dd}}{\partial \ln \eta}\right) \tag{14}$$

which suggests that an importer's environmental regulation also affects bilateral trade share. If $\gamma > \alpha\mu$, then Equation (14) is less than 0, stricter environmental regulation generates relatively stronger domestic competition in environment-intensive industries towards environmental goods, and strengthens these industries' comparative advantages in environment compared to other importers. Thus, goods become more difficult to be

[19] See Appendix A.2 (III) for the proof of Proposition 1.

[20] See Appendix A.2 (IV) for the proof of Proposition 2. The value of $1 + \frac{\partial \ln \pi_{dd}}{\partial \ln \eta}$ is greater than -1.

imported in these high-η industries in importer d. If $\gamma < \alpha\mu$, then Equation (14) is greater than 0, stricter environmental regulation weakens comparative advantages of environment in high-η industries, causing more foreign products to be importer in these industries.

We next investigate the effects of environmental regulation on the price of varieties in bilateral trade, which can be shown in the following propositions.

PROPOSITION 3. *Conditional on an importer d, a country's stringency of environmental regulation has no explicit impacts on its export prices in environment-intensive industries.*[21]

$$\left.\frac{\partial^2 \ln P_{do}}{\partial \delta_o \partial \eta}\right|_d = 0 \tag{15}$$

This prediction can be explained by the fact that when given an importer d, the bilateral trade price from d to o is determined by the price index Φ_d, which is shown in Equation (12).

PROPOSITION 4. *Conditional on an exporter o: If $\gamma > \alpha\mu$, the technique effects dominate the substitution effects, then a country with more stringent environmental regulation imports at a relatively lower price from o in environment-intensive industries. If $\gamma < \alpha\mu$, the substitution effects dominate the technique effects, then a country with more stringent environmental regulation imports at a relatively higher price from o in environment-intensive industries.*[22]

$$\left.\frac{\partial^2 \ln P_{do}}{\partial \ln(1+\delta_d)\partial \eta}\right|_o = -(\gamma - \alpha\mu)\cdot \pi_{dd} \cdot \left(1 + \frac{\partial \ln \pi_{dd}}{\partial \ln \eta}\right) \tag{16}$$

This equation suggests that if the technique effects dominate, then Equation (16) is less than 0, a high δ_d constitutes the importer's higher comparative advantages in environment in environment-intensive industries. Therefore, the costs of domestic production are lower, causing that only foreign products with lower prices can be imported. If the substitution effects dominate, then Equation (16) is greater than 0, the prediction turns to the opposite

[21] See Appendix A.2 (V) for the proof of Proposition 3.
[22] See Appendix A.2 (VI) for the proof of Proposition 4.

side in which stricter environmental regulation increases the trade price of varieties imported in environment-intensive industries.

The theoretical framework so far has modeled the effects of environmental regulation on a country's trade shares and trade prices across industries with different environmental intensity. Importantly, we reveal that the comparative advantages generated by environmental regulation depend on the competing force between the technique effects based on the Porter hypothesis and substitution effects based on the pollution haven hypothesis. Specifically, if the technique effects are greater than the substitution effects, an increase in environmental regulation stringency can improve production efficiency through technological progress, thus enhancing a country's comparative advantages in environment. In contrast, stricter environmental regulation reduces the comparative advantages with additional compliance costs.[23]

3. Empirical Strategy

Our model implies connections between environmental regulation and bilateral trade, which is empirically testable. Following previous related work (Cui et al., 2022; Romalis, 2004; Nunn, 2007; Chor, 2010), we try to document empirical evidence to test theoretical propositions with cross-country variations in environmental regulation and cross-industry variations in environmental intensity. This section first sets our empirical specification, and designs an identification strategy by constructing an instrumental variable for environmental regulation with meteorological records.

3.1. Baseline Specification

To investigate the effects of environmental regulation on export margins across industries with different environmental intensity, we consider the following empirical framework,[24]

[23] There is another condition for our propositions, which is the technique effects are equal to the substitution effects if $\gamma = \alpha\mu$. For brevity, we do not stress discussing this special case in which environmental regulation does not explicitly affect comparative advantages in environment, thus impacting trade.

[24] We construct dependent variables at the industry level with different concordances. Specifically, bilateral trade share is calculated at the U.S. 6-digit I-O level. Bilateral trade price is computed at the SITC 4-digit level, which is more informative for classifying more detailed industries or products. The details of variables construction are introduced later in this section. In the sequential empirical analysis, we call these variables of bilateral trade at the industry level.

$$Trade_{do}^{g} = \beta_{E1} \cdot ER_o \times \eta^g + \beta_{E2} \cdot JQ_o \times j^g + \beta_{E3} \cdot H_o \times h^g + \beta_{E4} \cdot K_o \times k^g + \zeta_d^g + \zeta_o + \mathbf{X}_o^g + \mathbf{B}_{do}^g + \varepsilon_{Edo}^g \tag{17}$$

where o, d, g refer to exporter, importer, industry, respectively. $Trade_{do}^{g}$ is bilateral trade share or price. $ER_o \times \eta^g$ is the regressor of interest, capturing differential effects of environmental regulation on export margins across industries that differ in environmental intensity, where ER_o denotes the environmental regulation stringency of exporter o, and η^g is the environmental intensity of industry g. Similar to Cui et al. (2022), we select the following three variables to control for other possible comparative advantages. JQ_o is exporter o's judicial quality, H_o and K_o are exporter o's skill and capital endowments, respectively. Correspondingly, j^g, h^g and k^g denote the contract, skill and capital intensity of industry g. The estimated coefficients β_{E1}, β_{E2}, β_{E3} and β_{E4} are identified by the variations across exporters within an importer-industry cell. We include the importer-industry fixed effects ζ_d^g to control for demand-side unobservable factors.[25] In addition, exporter fixed effects ζ_o are included to control for exporter's specific characteristics. $\mathbf{X}_o^g$ are a vector of control variables at the exporter-industry level.[26] $\mathbf{B}_{do}^g$ are a vector of variables capturing bilateral trade costs.[27] ε_{Edo}^g is the stochastic error term.

Similarly, the effects of environmental regulation stringency on import margins across industries or products with different environmental intensity can be investigated in the following specification,

$$Trade_{do}^{g} = \beta_{I1} \cdot ER_d \times \eta^g + \beta_{I2} \cdot JQ_{dI} \times j^g + \beta_{I2} \cdot H_{dI} \times h^g + \beta_{I3} \cdot K_d \times k^g + \zeta_o^g + \zeta_d + \mathbf{X}_d^g + \mathbf{B}_{do}^g + \varepsilon_{Ido}^g \tag{18}$$

The coefficient β_{I1} of the interaction term $ER_d \times \eta^g$ is our interest, which estimates the differential impacts of environmental regulation of importers on import margins across

[25] The existing literature on comparative advantages seldom considers demand-side confounding factors, which may bias the estimated results. This specification addresses the issue by including the refined fixed effects to control for all industry-level factors of the importer, such as industrial structure, consumption preferences, and market concentration.

[26] The country-industry level control variables include the interaction between country-level financial development and industry-level external financial dependence, and the interactions between country-level GDP per capita (taking logarithm) and several industry-level characteristics, including the value-added share, intra-industry trade share, production complexity, and TFP growth.

[27] The bilateral control variables in the regressions include trade tariff, bilateral distance, and whether the exporter and importer share the border, have a common official language, own colonial tie, are in the common currency union, and the common FTA.

industries with different environmental intensity. Thus, we are able to estimate coefficients β_{I1}, β_{I2}, β_{I3} and β_{I4} using the variations across importers within an exporter-industry cell. Likewise, we include exporter-industry fixed effects ζ_o^g to control for supply-side confounding factors, such as production efficiency. And we add importer fixed effects ζ_d to absorb any effects of an importer's specific characteristics. $\mathbf{X}_d^g$ are a vector of control variables at the importer-industry level, and $\mathbf{B}_{do}^g$ are also included to control for bilateral trade costs. ε_{Ido}^g is the stochastic error term.

3.2. Empirical Strategy

In the baseline specifications, environmental regulation could have a reverse endogeneity on bilateral trade. That is, a country might enact and enforce more stringent environmental regulation if environmental goods are occupied a major market share in this country for either exports or imports. To address this endogeneity problem, we adopt an instrumental variable approach to identify the causal effects by constructing an instrument for environmental regulation.

The rationale for the instrumental variable employed in this paper is as follows. Climate change causes many severe environmental problems, such as global warming, forest degradation, and biodiversity loss, thus threatening sustainable economic activities.[28] It greatly arouses people's attention to environmental protection and drives governments to adopt environmental regulation. Since the 1990s, the UN has called a series of international conferences to recall the international community to propose environmental policies to address environmental problems through signing legally binding agreements, including the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, the Kyoto Protocol in 1997.[29] As a result, countries around the world have gradually adopted rigorous

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[28] There is difficulty in analyzing the economic impacts of environmental problems accurately since environmental costs can be categorized into many aspects, such as assessment costs for environmental studies and analysis, prevention costs incurred in operations which prevent environmental impacts, mitigation costs for both new and existing activities, reclamation costs for returning the affected sites to the original state, compensation costs to affected parties for irrecoverable damage to the environment. We seek to illustrate the costs of environmental issues by climate change through a statistic. According to the analysis of the European Environment Agency, the climate-related hazards caused economic losses totaling an estimated 487 billion euros in the EU members.

[29] The UNFCCC was signed by 154 states, and entered into force in 1994. As an extension of the UNFCCC, the Kyoto Protocol, which attached more attention to the global warming issue was signed by 192 states, and entered into force in 2005.

environmental policies to tackle pressing environmental issues brought by climate change.[30] We argue that countries that experience extreme climate change are more likely to tighten environmental regulation.[31] Temperature variation is a major part and a common measure of climate change pioneered by Schlenker and Roberts (2006), and Deschênes and Greenstone (2007).[32] Therefore, temperature anomalies that capture the degree of temperature variation are a determinant for conducting environmental regulation. Following Dell et al. (2012), we construct a variable, temperature anomalies, which is defined as the standard deviation of annual temperature from 1950 to 1990, to measure the variation in temperature change of each country. In the empirical analysis, we employ the constructed variable as an instrument for environmental regulation.

Because we use cross-section data in 1997 in the baseline estimations, the constructed instrument is predetermined before the sample, which is unlikely to be affected by bilateral trade and other economic shocks during the sample period.[33] In addition, we carefully include two sets of control variables and refine fixed effects to control for other potential channels through which temperature anomalies may affect a country's trade.

Since our focus is on the interaction between environmental regulation of exporter or importer and industries' environmental intensity, we instrument the two interactions in Equations (17) and (18), respectively, using the interaction between temperature anomalies of exporter or importer and industries' environmental intensity.

4. Data

[30] For example, developed economies have stressed the policies and actions of tackling environmental challenges. The stringency of environmental regulation tripled across OCED countries between 1995 and 2015 (OECD, 2021).

[31] Generally, countries suffering from climate change are more likely to solve this issue. For example, Japan and Germany, which were hit by severe heat waves in the past decades, developed strict environmental standards and carried out strong environmental regulations. Moreover, we show the positive relationship between temperature anomalies and environmental regulation stringency in Appendix Figure B1 and the first-stage estimates in Table 2.

[32] As noted in Dell et al. (2012), the word "climate" refers to the long-run distribution of temperature.

[33] To gauge this, we calculate the correlation between the instrument and the dependent variables. We find that the correlation between temperature anomalies and bilateral trade shares is only 0.052, and the correlation between temperature anomalies and bilateral trade prices is only 0.029. We plot these two pairs of relationships in Appendix Figures B2 and B3, respectively.

This section describes the data used in the empirical analysis. The descriptive statistics of main variables are reported in Appendix Table B1.

4.1. Trade Share and Trade Price

The data on trade shares and prices of two paired countries are taken from Cui et al. (2022). Specifically, bilateral trade data for the 4-digit code of the Standard International Trade Classification (SITC) Revision 2 are drawn from the UN Comtrade data. The sample contains 198 countries and 1,186 unique combinations of the SITC 4-digit code and the unit of measurement. The trade data are mapped to the U.S. Bureau of Economic Analysis (BEA) I-O industry classification of 225 I-O industries in 1997. This paper uses the BEA I-O industry classification to define industries with respect to bilateral trade share. To measure industry-level bilateral trade share π_{do}^{g}, we adopt the following procedures. First, calculate the share of importer d's import value from exporter o in d's total import value for each industry g. Second, use the World Input-Output Database (WIOD) to calculate the share of importer d's total import value from all other exporting countries over total absorption in each WIOD sector for each country, which is then mapped to the BEA I-O industry. Third, the bilateral trade share π_{do}^{g} at the industry level is calculated by multiplying the importer d's import share from exporter o by the total import share of importer d from all other exporters in the BEA I-O industry. The price or unit value of bilateral trade is calculated at the SITC 4-digit subgroup (industry) level.[34] Bilateral trade price is computed as bilateral trade value divided by bilateral traded quantity. Finally, the data on trade share and price are corrected for measurement errors as in Cui et al. (2022).

4.2. Environmental Regulation

Following Kellenberg (2009), and Wagner and Timmins (2009), the variable for environmental regulation stringency employed in this paper is constructed using survey data from the Global Competitiveness Report (GCR) published by the World Economic Forum (WEF). The WEF has been surveying on environmental issues since the mid-1990, while the early version of questions on environmental policy are not directly comparable to the later years' survey

[34] Each SITC 4-digit code contains a subgroup of approximate products, while technically does not represents an industry. We prefer regarding each of the subgroups as an industry for consistent expression where the measures of bilateral trade share are constructed at BEA I-O industry level, and the measure of bilateral trade price is constructed at the SITC 4-digit industry level.

questions because the questionnaires have changed during the period. Two questions in GCR have been available since 2000 that directly measure the stringency of environmental regulation across surveyed countries: (1) stringency of environmental regulation in your country; (2) consistency of enforcement of the environmental regulation in your country.[35] Following Kellenberg (2009), the variable measuring environmental regulation stringency, ER, is constructed by multiplying the score of the above two questions, which captures both the stringency and the enforcement of environmental regulation. The constructed variable ER in the main analysis covers 59 countries in 1999.[36]

The advantage of the survey of GCR is that it is the only dataset that provides a measure of both the stringency and enforcement levels of environmental regulation across countries. In addition, it is a survey of a representative sample of business leaders in their respective countries with a reliable methodology, including sampling, data editing and calculation.[37] Therefore, the GCR data gauges a more valuable measure of environmental policy across countries, which is less likely to be captured in other measures, such as abatement costs, and emissions.[38]

[35] Each survey question is ranked on a score of 1 (the laxest) to 7 (the most stringent). It means that countries with both high stringency of environmental regulation score and enforcement score receive the highest environmental regulation stringency measure.

[36] We argue that the country-level environmental regulation stringency does not vary dramatically in the short term for that we use the constructed variable of environmental regulation stringency in 1999 while other variables in 1997 in the baseline regressions. We conduct two tests to alleviate the concern. First, we check the variation in environmental regulation stringency measure of each country using series data, and keep the sample with stable environmental regulation to re-estimate the model. Second, we construct panel data from 1997 to 2011 to back up the baseline specification.

[37] The GCR has taken a number of procedures to ensure the accuracy of measures by taking representative samples across industries in each country based on employment, firm size, and firm nationality. Importantly, the survey and hard data track each other quite closely, such as environmental stringency, which strongly shows its reliability (Kellenberg, 2009). Also, a bunch of previous studies have used variables from the GCR survey to estimate various impacts on multinational activity (e.g., Carr et al., 2001; Markusen and Maskus, 2002; Blonigen et al., 2003; Yeaple, 2003; Ekholm et al., 2007; Kellenberg, 2009; Chung, 2014).

[38] Previous studies document that environmental regulation's impacts on international trade and investment using abatement costs across states in the U.S. (List and Co, 2000; Keller and Levinson, 2002; Ederington and Minier, 2003; Ederington et al., 2004, 2005; Levinson and Taylor, 2008; Rubashkina et al., 2015). However, this indicator is limited since it is not well developed for other countries except for the U.S., European and Asia-Pacific countries, and is not readily comparable across countries due to differences in survey methodologies (Dechezleprêtre and Sato, 2017). As an alternative, some research employs a measure of emissions as a proxy for cross-country differences in environmental regulation, such as carbon dioxide emissions, sulfur dioxide emissions, and energy intensity (Eskeland and Harrison, 2003; Xing and Kolstad, 2002; Co et al., 2004; Shapiro and Walker, 2018). Kellenberg (2009) argues that these measures can only capture one component of environmental regulation and have shortcomings.

4.3. Environmental Intensity

We calculate industries' environmental intensity by defining environmental goods with using the Input-Output table. We use the Combined List of Environmental Goods (CLEG) developed by OECD (Sauvage, 2014), which classifies environmental goods at the HS 6-digit level. It is a combined list of environmental goods in the Friends' list from the World Trade Organization (WTO), APEC list from the Asia-Pacific Economic Cooperation (APEC), and Plurilateral agreement on environmental goods and services (PEGS) list from OECD.[39] The CLEG list 248 environmental products in trade at the HS 6-digit level, such as machinery for filtering or purifying water, machinery for filtering or purifying gases, and industrial furnaces and ovens.

There are procedures for calculating environmental intensity at the industry level. First, we match each environmental product in the CLEG list to the BEA I-O industry with the HS 10-digit code to BEA I-O industry concordance from the BEA. Second, we use the 1997 U.S. Input-Output Use Table (489 industries) to identify which intermediate inputs are used and what amount in the production of each final good.[40] Third, because some intermediate inputs are environmental goods while others are not, we can calculate the share of environmental input for each industry as the measure of environmental intensity.

4.4. Controls Variables

Measures of contract intensity, skill intensity and capital intensity are drawn from Nunn (2007), as well as industry characteristics, including value-added share, intra-industry trade share, productivity growth, and Herfindahl index of input concentration. The measure of external finance dependence follows Rajan and Zingales (1998).[41] Country-level judicial quality measure is taken from Cui et al. (2022), and country-level skill endowment, capital endowment, financial development, and per capita income are also from Nunn (2007).

[39] There is no internationally agreed list of environmental goods due to many difficulties, such as the lack of specificity of existing classifications, and the existence of products with multiple uses (Steenblik, 2005). Besides, the proposed lists of environmental goods are always the subject of trade negotiations, which excludes a number of goods generally deemed environmental (Sauvage, 2014). The CLEG addresses these issues by classifying goods at the HS product level based on the environmental theme or medium.

[40] Because highly disaggregated I-O tables do not exist for all countries when constructing the measure of industry-level environmental intensity, we must use the U.S. Input-Output Use Table for all countries, implicitly assuming that other countries' structures of intermediate input are the same as in the U.S. In the light of Nunn (2007), we calculate the similarity of industry structure to deal with this issue with a robustness test.

[41] These variables are all at the BEA I-O industry level. Accordingly, we map them to the SITC 4-digit level using bilateral trade prices as the dependent variable.

Bilateral tariff data at the SITC 4-digit level are from the UN Comtrade. Data on bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA from the CEPII database are from Cui et al. (2022).

4.5. Temperature Anomalies

The historical temperature data are taken from Dell et al. (2012), and Cattaneo and Peri (2016). Following Dell et al. (2012), we calculate the standard deviation of each country's annual temperature between 1950 and 1990 to measure its temperature anomalies.[42] Specifically, the monthly terrestrial temperature data at 0.5 × 0.5 degree resolution are aggregated to the country-year level using the population at the resolution as weights.[43]

5. Empirical Results

In this section, we first test the theoretical propositions with respect to bilateral trade share and trade prices with the OLS estimator. And then, we estimate the model with the IV approach using the constructed instrument. All the explanatory variables are standardized to directly compare their relative importance (Nunn, 2007; Cui et al., 2022).

5.1. OLS Regressions

Table 1 examines the predictions by reporting the OLS estimates of baseline model. In particular, using the bilateral trade share as the dependent variable, column (1) tests Proposition 1, and column (3) tests Proposition 2, illustrating whether a country with stricter environmental regulation exports or imports more in environment-intensive industries. Columns (2) and (4) test Proposition 3 and 4, respectively, with the bilateral trade price as the dependent variable, investigating whether a country with stricter environmental regulation exports or imports at higher prices in environment-intensive industries. Each column in addition to interaction between environmental regulation and environmental intensity, includes justice interaction, skill interaction and capital interaction of the exporter or importer to control for justice-based, skill-based and capital-based comparative advantages, and

[42] Compared to absolute variation in temperature that might be led by the global tendency of climate change, temperature anomalies can capture the temperature volatility in different short periods during the long run. Thus, this indicator is more likely to capture temperature change caused by human activities.

[43] The temperature data are drawn from Terrestrial Air Temperature and Precipitation: 1900–2006 Gridded Monthly Time Series, Version 1.01 (Matsuura and Willmott, 2007). And the weights are constructed with data from the Global Rural-Urban Mapping Project.

bilateral control variables. The interaction of country-level financial development with industry-level external finance dependence, and the interactions of country-level log per capita income with several industry-level characteristics are also controlled in the regressions.

The estimated coefficients of the exporter's environmental regulation interaction, $ER_o \times \eta^g$, in column (1) in Table 1 is positive and statistically significant at the 1% level. The results suggest that an exporter with more stringent environmental regulation exports relatively more in environment-intensive industries, which is on the basis that the effects of the Porter hypothesis dominate the effects of the pollution haven hypothesis. In column (2), we use bilateral trade prices as the dependent variable, and find that the correlation between environmental regulation and trade prices in environment-intensive industries is not statistically significant. The coefficients of importer's environmental regulation interaction, $ER_d \times \eta^g$, in columns (3) and (4) in Table 1 are all negative and statistically significant at the 1% level. [44] These estimation results show that an importer with more stringent environmental regulation imports relatives less and at a lower price in the environment-intensive industries, which also confirms that the effects of the Porter hypothesis play a more dominant role in our sample on average. The above estimation results highly support our theoretical propositions based on the condition that technique effects dominate the substitution effects.

5.2. IV Regressions

We next investigate the causal effects of environmental regulation on bilateral trade share and prices by using temperature anomalies as the instrument for environmental regulation. The IV estimates in Panel A of Table 2 are consistent with the OLS estimates, while all the coefficients of key explanatory variables become larger. For the economic magnitude, a one standard deviation increase in interaction between export's environmental regulation stringency and industry's environmental intensity, $ER_o \times \eta^g$, increases bilateral trade shares by 107%. For the importer, a one standard deviation increase in interaction between importer's environmental regulation stringency and industry's environmental intensity,

[44] The estimated coefficients of justice, skill and capital interactions align with Cui et al. (2022).

$ER_d \times \eta^g$, decreases bilateral trade shares and trade prices by 107% and 27.6%, respectively.[45]

The first-stage estimates in Panel B of Table 2 show that the Kleibergen-Paap (K-P) *F*-statistics are all greater than 10, which rejects the null hypothesis that the instrumental variable is subject to the weak IV problem. The coefficients in the first-stage estimation are all positive and statistically significant, supporting the prediction that countries with stronger temperature anomalies are likely to execute stricter environmental regulation. These statistical tests support that temperature anomalies are a valid instrument for environmental regulation.

Overall, the OLS and IV estimates examine the theoretical propositions with the exporter-importer-industry specifications. On average, in our sample, a country with stricter environmental regulation exports relatively more, while imports relatively less and at a lower price in environment-intensive industries. It is a Heckscher-Ohlin effect in terms of environment.[46] These estimation results suggest that the effects of the Porter hypothesis dominate the effects of the pollution haven hypothesis in our sample. In that case, environmental regulation can strengthen a country's comparative advantage in environment.

6. Further Discussions on Empirical Results

In this section, a bunch of robustness tests are performed. Next, we investigate the heterogeneity of the effects of environmental regulation on trade between large and small destination countries. Finally, we examine the quasi-Rybczynski effects of environmental regulation.

6.1. Robustness Tests

[45] We re-estimate the IV regressions by clustering the standard errors at the export-importer level. The estimation results reported in Appendix Table B2 hold.

[46] Following Romalis (2004), we visualize the Heckscher-Ohlin effect of environmental regulation with an example. Specially, we compare the global trade share across industries with different environmental intensity from an exporter with high environmental regulation stringency and an exporter with low environmental regulation stringency in 1997. As shown in Appendix Figure B4, countries with stricter environmental regulation, such as Singapore, which ranked 9th out of 128 countries on environmental regulation between 1997 and 2007, obtain larger shares in the global market in high-η industries, while smaller shares in low-η industries. In contrast, Bangladesh ranked 112th in the sample shows an opposite pattern.

After establishing the baseline results, we conduct a set of checks to test the robustness of our findings regarding some concerns in the baseline model, including the sample, specifications, and measures.

6.1.1. Panel Data

To ensure whether the conclusions still hold in more recent years, we use a panel data sample from 1997 to 2007 to investigate the effects of environmental regulation on bilateral trade shares and prices.[47] In particular, we include importer-industry-year and exporter-year fixed effects for estimating exporter's environmental regulation effects so that the coefficients are identified using variations across exporters within an importer-industry-year cell.[48] Similarly, we include exporter-industry-year and importer-year fixed effects for estimating importers' environmental regulation effects. Other settings are similar to the baseline specifications.[49] The estimation results of panel data are shown in Table 3. We obtain qualitatively robust results with the cross-section estimates. Specifically, the export's interaction between environmental regulation stringency and industry's environmental intensity has positive and statistically significant effects on trade share at the 1% level, while having insignificant effects on trade price. And the import's interaction between environmental regulation stringency and industry's environmental intensity has negative and statistically significant effects on both trade share and trade prices at the 1% level.[50] Overall, the estimation results support the baseline results by extending the sample period.

6.1.2. Discussion on Environmental Regulation

[47] As argued in Section 4, we find that the variation of environmental regulation stringency across years of a specific given country is pretty limited, which also shows the reasonability of cross-section estimation in the baseline specifications. The panel data estimation can further control for the year specific unobservable factors.

[48] The empirical specifications for exporter and importer are as follows: $Trade^{g}_{do,t} = \beta_{E1} \cdot ER_{o,t} \times \eta^{g}_{t} + \beta_{E2} \cdot JQ_{o,t} \times j^{g}_{t} + \beta_{E3} \cdot H_{o,t} \times h^{g}_{t} + \beta_{E4} \cdot K_{o,t} \times k^{g}_{t} + \zeta^{g}_{d,t} + \zeta_{o,t} + \mathbf{X}^{g}_{o,t} + \mathbf{B}^{g}_{do,t} + \varepsilon^{g}_{Edo,t}$, and $Trade^{g}_{do,t} = \lambda_{I1} \cdot ER_{d,t} \times \eta^{g}_{t} + \lambda_{I2} \cdot JQ_{d,t} \times j^{g}_{t} + \lambda_{I3} \cdot H_{d,t} \times h^{g}_{t} + \lambda_{I4} \cdot K_{d,t} \times k^{g}_{t} + \zeta^{g}_{o,t} + \zeta_{d,t} + \mathbf{X}^{g}_{d,t} + \mathbf{B}^{g}_{do,t} + \varepsilon^{g}_{Ido,t}$, where t denotes year.

[49] Details of panel data construction refer to Cui et al. (2022). The number of countries in our sample increases from 58 in 1997 to 128 in 2007.

[50] The above panel data estimates might be somewhat biased since each industry's environmental intensity is assumed time-invariant. We thus re-calculate industry-level environmental intensity in different years to fit the panel data. In particular, we calculate each industry's environmental intensity with the U.S. I-O Use Table in 1997, 2002, and 2007. And then, compute this variable for each year between 1997 and 2007 using the moving average method. Therefore, we obtain the indicator at a yearly frequency, and re-estimate the panel data model in Appendix Table B3. The estimates are robust to the previous results.

As mentioned, one may worry that the environmental regulation stringency in 1999 employed in the baseline model is not accurate since other variables are calculated in 1997. Using the GCR survey data from 1999-2007, we identify the consistency degree of a country's environmental regulation stringency with the variations in the score of environmental regulation stringency. Then we classify countries into two groups with the median as the criteria, namely high-consistency and low-consistency of environmental regulation stringency.[51] The high-consistency group is likely to reflect the actual results more accurately. We drop observations with low consistency of environmental regulation for the plausible estimation bias. The estimation results in Table 4 are aligned with our main findings.

6.1.3. Discussion on Environmental Intensity

Since there are no disaggregated industry-level input-output data for all countries, we assume that the industry structure of observations in our sample is similar to the U.S. in the baseline specifications. It means the environmental intensity of a specific industry η^g for all countries is the same in our sample. In order to deal with the potential bias brought by differences in environmental intensity, we follow Nunn (2007) to calculate the similarity of industry structure for each country compared to the U.S. by using Global Trade Analysis Project (GTAP) Data Base in 1997 that provides I-O tables for 57 countries.[52] We then re-estimate the baseline equation after restricting the sample to include only countries with I-O tables most similar to the U.S. I-O Use Table. After dealing with the concern about differences in industrial structure, the estimated results in Table 5 show that the estimated results do not rely on the particular assumption of environmental intensity.[53]

The environmental intensity of industry is a continuous variable following our calculation method. To better classify whether an industry is an environment-intensive industry, we

[51] The surveyed countries in the sample of 1999 are mostly categorized into the high-consistency of environmental regulation stringency group so that observations in the estimations do not decrease so much.

[52] For 46 countries in our sample, I-O tables in 1997 disaggregated into 57 sectors are available from the GTAP data. To construct a measure of similarity to the U.S. I-O Use Table, we follow the calculation in Elmslie and Milberg (1992), and Nunn (2007). We take the vector of final goods produced in the U.S. in 1997, and using the U.S. GTAP I-O table, we calculate the amount of each intermediate input needed to produce this output vector. For every other country for which a GTAP I-O table exists, we use the country's I-O table to calculate the amount of each intermediate input needed to produce the same output vector. We then compare each country's input vector with the U.S. input vector by calculating the pairwise correlation coefficient of the two vectors.

[53] We use the similarity of industrial structure, 0.5, as the criteria in Table 5. We also perform a sensitive test by using similarity index 0.6 as the criteria. The estimation results reported in Appendix Table B4 are robust.

define a dummy variable to indicate that. In particular, we employ the median of the environmental intensity of all industries as the criteria, and then identify an industry as an environment-intensive industry if its environmental intensity is greater than the median. The estimation results reported in Table 6 show similar patterns to the baseline regressions.

Another concern about the calculation of the industry's environmental intensity is that although covering products having environmental applications, the CLEG has a possibility of including products used for non-environmental purposes. This is partly because most HS lines do not identify all categories of traded goods uniquely, resulting in that a specific 6-digit HS code may contain both products having environmental applications and others that do not. Thus, using the CLEG plausibly faces a trade-off between comprehensiveness and accuracy in defining the scope of environmental goods (Sauvage, 2014). Recognizing the need to deal with the trade-off, we seek to perform a robustness test using an alternative list that identifies environmental goods in a narrower scope, namely the Core CLEG.[54] Then, we calculate the industry's environmental intensity using the Core CLEG, and re-estimate the baseline equation. As shown in Table 7, the results are in line with the estimates of using the CLEG, complementing the main results.

6.1.4. Alternative Measures

We try to employ other measures of key variables in our main analyses to test whether the baseline results are robust. As for environmental regulation, we choose a composite indicator, Environmental Performance Index (EPI), as a proxy variable, and report the regression results in Table 8.[55] The estimated results show that a country with stricter environmental regulation exports more, while imports less and at a lower price. These checks tell us that the baseline results do not rely on the specific measure of environmental regulation stringency.

Turning to the dependent variables, we calculate the indicators using the Cost Insurance and Freight (CIF) method in the baseline regressions to capture the *ad valorem* cost in trade.

[54] The Core CLEG is selected from the scope of the CLEG with expert advice from Environmental Business International Incorporation (EBI). OECD reassessed each product in the CLEG with data from EBI on the size of the global market for various environmental pieces of equipment. It ascertains which HS codes on the CLEG have a clear environmental content regarding the value of the trade flows they measure. The reduced HS codes of the Core CLEG still cover more than two-thirds of trade flows.

[55] The dataset is developed by Yale Center for Environmental Law, and Policy and Center for International Earth Science Information Network Earth Institute, Columbia University. Using 32 performance indicators across 11 issue categories, the EPI ranks 180 countries on environmental health and ecosystem vitality. These indicators gauge how close countries are to established environmental policy targets on a national scale. Data are available at https://epi.yale.edu.

In order to confirm that the results are not driven by the particular calculation of trade shares and trade prices, we calculate variables with the Free on Board (FOB) method in the robustness test. The estimation results using dependent variables calculated by the FOB method are reported in Appendix Table B5. Still, we find similar regression results.

6.2. Heterogenous Effects Across Destinations

This part of empirical analysis examines whether the effects of environmental regulation on trade shares and prices across industries with different environmental intensity are heterogenous across different destinations. In particular, we categorize importers into large and small importers employing whether a destination country ranks top 10% of GDP as the criteria.[56] To explore the potential heterogenous effects, we add an interaction by multiplying the exporter or importer's environmental regulation stringency, industry's environmental intensity, and the dummy indicating whether the importer is a large destination country. The estimation results reported in Table 9 show no statistically significant difference in trade shares or prices between different destinations.

6.3. Quasi-Rybczynski Effects

Our empirical evidence verifies the propositions from the theory on the condition where the effects of Porter hypothesis play a more dominant role. We seek to investigate how the competing force evolves with an ongoing tightening of environmental regulation. Following the procedures in Romalis (2004), we first select a group of economies with the fastest-growing environmental regulation stringency, and then investigate the dynamic effect of environmental regulation across industries with different environmental intensity. The visualization of the Rybczynski effects of environmental regulation is plotted in Figure 1. It demonstrates that the export structure has changed with increased environmental regulation stringency. In particular, the export shares of the above group shift from industries of low environmental intensity to industries of high environmental intensity between 1997 and 2007.[57] This finding is a reflection of quasi-Rybczynski effects, which further offers suggestive

[56] We use the top 20% of GDP as the criteria to identify whether a destination country is large, the estimation results reported in Appendix Table B6 remain.

[57] We also use the EPI index to identify the group of fast-growing countries regarding environmental regulation stringency. The average annual growth rates of the EPI index of these countries are greater than 1%. The results reported in Appendix Figure B5 show similar patterns.

evidence that compared with substitution effects from the pollution haven hypothesis, the technique effects brought from environmental regulation are more pronounced.

7. Conclusions

Based on two debated hypotheses of environmental regulation, the Porter hypothesis and the pollution haven hypothesis, this paper introduces the effects of technological progress and compliance costs into the production of environmental goods. The relative price of products between environmental and non-environmental sectors will change when environmental regulation enters. It thus shapes comparative advantages in environmental of a country. We then embed the two-sector production process into a Ricardian trade model to understand how a country's environmental regulation affects trade shares and prices. The theoretical analysis shows that the impacts of environmental regulation on trade are determined by the competing force of technique effects and substitution effects.

In empirics, we construct country-level environmental regulation stringency with the survey data from the WEC, and industry-level environmental intensity using the CLEG and I-O table. In order to address the endogeneity issues, we calculate each country's temperature anomalies as the instrument for environmental regulation stringency. This paper empirically suggests that the effects of the Porter hypothesis dominate the effects of the pollution haven hypothesis when enacting environmental regulation. The findings indicate that a country's environmental regulation can increase comparative advantages of environment. In that case, a country with more stringent environmental regulation exports relatively more, while imports relatively less and at a lower price.

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Tables and Figures

Table 1 OLS estimates of the effects of environmental regulation on trade

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Environment: $ER \times \eta$	0.614***	0.035	-0.423***	-0.106***
	(0.126)	(0.052)	(0.123)	(0.029)
Justice: $JQ \times j$	0.711***	-0.024	-0.077	0.080***
	(0.160)	(0.051)	(0.062)	(0.025)
Skill: $H \times h$	0.188**	0.003	-0.163***	0.001
	(0.083)	(0.023)	(0.036)	(0.014)
Capital: $K \times k$	0.135	-0.204***	-0.200***	-0.002
	(0.128)	(0.043)	(0.054)	(0.046)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
R-squared	0.182	0.021	0.250	0.029
Observations	206,927	410,102	140,216	294,900

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 2 IV estimates of the effects of environmental regulation on trade

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Panel A. Second-stage estimates				
Environment: $ER \times \eta$	1.066***	-0.163	-1.073***	-0.276***
	(0.264)	(0.148)	(0.236)	(0.075)
Justice: $JQ \times j$	0.772***	0.004	-0.157**	0.054*
	(0.175)	(0.023)	(0.069)	(0.030)
Skill: $H \times h$	0.188**	-0.053	-0.161***	0.001
	(0.083)	(0.059)	(0.037)	(0.014)
Capital: $K \times k$	0.113	-0.186***	-0.162***	0.017
	(0.122)	(0.044)	(0.056)	(0.047)
Panel B. First-stage estimates				
Dependent variable:	$\eta^g \times ER$	$\eta^g \times ER$	$\eta^g \times ER$	$\eta^g \times ER$
$\eta^g \times TA$	0.179***	0.173***	0.192***	0.185***
	(0.042)	(0.044)	(0.036)	(0.037)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	18.449	15.728	27.777	24.673
Observations	206,927	140,216	140,216	294,900

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3 Panel data estimation 1997-2007

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Environment: $ER \times \eta$	0.661***	-0.078	-0.620***	-0.126***
	(0.180)	(0.098)	(0.109)	(0.039)
Justice: $JQ \times j$	0.278***	0.022	-0.118***	-0.007
	(0.090)	(0.044)	(0.029)	(0.019)
Skill: $H \times h$	0.623***	-0.026	-0.124***	-0.001
	(0.136)	(0.049)	(0.037)	(0.016)
Capital: $K \times k$	-0.066	-0.213***	0.219***	-0.037
	(0.182)	(0.077)	(0.062)	(0.041)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	41.488	35.939	70.199	64.656
Observations	2,649,787	5,161,246	2,011,814	4,030,231

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 4 Subsample of high-consistency of environmental regulation stringency

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Environment: $ER \times \eta$	1.151***	-0.216	-1.287***	-0.333***
	(0.366)	(0.190)	(0.381)	(0.110)
Justice: $JQ \times j$	0.705***	-0.048	-0.211**	0.033
	(0.222)	(0.083)	(0.098)	(0.050)
Skill: $H \times h$	0.167*	0.002	-0.159***	-0.005
	(0.096)	(0.026)	(0.043)	(0.018)
Capital: $K \times k$	0.155	-0.201***	-0.216***	0.004
	(0.146)	(0.049)	(0.072)	(0.062)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	11.833	10.250	15.624	13.646
Observations	190,838	381,836	118,385	252,797

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 5 Subsample of high similarity of industry structure to the U.S.

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Environment: $ER \times \eta$	0.983***	-0.116	-1.084***	-0.274***
	(0.249)	(0.144)	(0.270)	(0.085)
Justice: $JQ \times j$	0.743***	-0.033	-0.113	0.067*
	(0.182)	(0.059)	(0.079)	(0.037)
Skill: $H \times h$	0.142	0.018	-0.245***	-0.017
	(0.135)	(0.035)	(0.056)	(0.023)
Capital: $K \times k$	0.061	-0.178***	-0.176**	0.060
	(0.131)	(0.033)	(0.077)	(0.052)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	14.427	12.728	20.043	18.510
Observations	176,777	349,540	111,041	236,012

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 6 Environmental intensity dummy

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Environment: $ER\ dummy \times \eta$	1.243***	-0.187	-1.249***	-0.325***
	(0.307)	(0.170)	(0.275)	(0.088)
Justice: $JQ \times j$	0.718***	0.002	-0.109*	0.074***
	(0.167)	(0.023)	(0.065)	(0.027)
Skill: $H \times h$	0.197**	-0.039	-0.168***	-0.003
	(0.083)	(0.054)	(0.037)	(0.015)
Capital: $K \times k$	0.116	-0.191***	-0.173***	0.006
	(0.122)	(0.044)	(0.055)	(0.046)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	18.162	16.728	28.159	26.110
Observations	209,927	410,102	140,216	294,900

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 7 Environmental intensity computed by Core CLEG

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Environment: $ER \times \eta$	0.756***	0.092	-0.866***	-0.214***
	(0.216)	(0.175)	(0.198)	(0.072)
Justice: $JQ \times j$	0.681***	-0.023	-0.084	0.079***
	(0.161)	(0.053)	(0.065)	(0.027)
Skill: $H \times h$	0.188**	0.003	-0.162***	-0.001
	(0.082)	(0.023)	(0.037)	(0.014)
Capital: $K \times k$	0.134	-0.210***	-0.192***	0.008
	(0.127)	(0.046)	(0.053)	(0.046)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	17.637	14.752	28.434	25.197
Observations	206,927	410,102	140,216	294,900

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 8 Alternative measure of environmental regulation (EPI index)

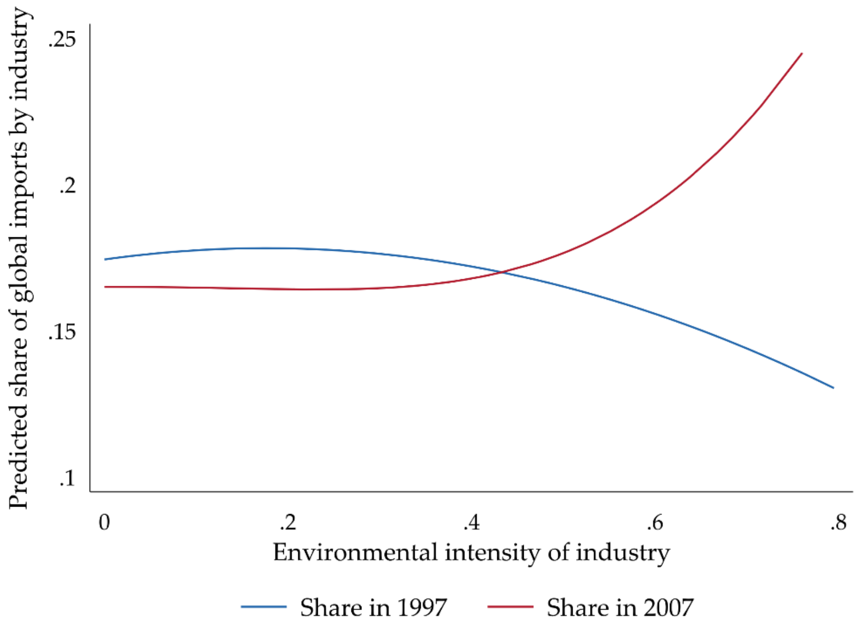
	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Environment: $ER \times \eta$	3.399***	-0.562	-3.994***	-0.993***
	(0.901)	(0.526)	(1.021)	(0.366)
Justice: $JQ \times j$	0.693***	-0.027	-0.161***	0.063**
	(0.144)	(0.050)	(0.057)	(0.025)
Skill: $H \times h$	0.197**	0.003	-0.131***	0.010
	(0.074)	(0.022)	(0.031)	(0.010)
Capital: $K \times k$	0.030	-0.124***	-0.089**	-0.001
	(0.109)	(0.040)	(0.043)	(0.030)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	16.058	14.663	17.442	15.326
Observations	209,942	411,112	161,118	329,542

Note: Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 9 Heterogeneity between large and small countries (top 10%)

	(1)	(2)	(3)	(4)
Indicator for:	Exporter	Exporter	Importer	Importer
Dependent variable:	Trade share	Trade price	Trade share	Trade price
Interaction: $ER \times \eta \times Large\ destination$	0.496	-0.007	0.022	0.016
	(0.380)	(0.077)	(0.022)	(0.012)
Environment: $ER \times \eta$	1.013***	-0.162	-1.074***	-0.276***
	(0.255)	(0.151)	(0.238)	(0.076)
Justice: $JQ \times j$	0.772***	-0.053	-0.154**	0.057*
	(0.176)	(0.059)	(0.070)	(0.029)
Skill: $H \times h$	0.188**	0.004	-0.161***	0.001
	(0.083)	(0.023)	(0.037)	(0.014)
Capital: $K \times k$	0.113	-0.186***	-0.162***	0.017
	(0.122)	(0.044)	(0.056)	(0.048)
Bilateral controls	Yes	Yes	Yes	Yes
Additional controls	Yes	Yes	Yes	Yes
Exporter FE	Yes	Yes		
Importer-industry FE	Yes	Yes		
Importer FE			Yes	Yes
Exporter-industry FE			Yes	Yes
Kleibergen-Paap *F*-statistic	9.216	7.591	13.355	11.914
Observations	209,927	410,102	140,216	294,900

Note: The interaction is instrumented by multiplying environmental intensity, temperature anomalies and the dummy indicating whether a destination is large. Bilateral controls include tariff, bilateral distance, shared border, common official language, colonial tie, common currency union, and common FTA. Additional controls include the financial interaction, the interactions of log per capita income with value-added share, intra-industry trade share, production complexity, and TFP growth. Standard errors reported in parentheses are clustered at the exporter level in columns (1) and (2), and clustered at the importer level in columns (3) and (4). *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.



Note: The red line denotes the fractional-polynomial prediction plots of shares of global imports by industry from the group of countries with the fastest-growing environmental regulation stringency in 1997, while the blue line denotes that in 2007.

Figure 1 Rybczynski effects for the group of countries with the fastest-growing environmental regulation stringency in 1997 and 2007