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Global Environmental Standards with Heterogeneous Polluters

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***Abstract*:** We introduce environmental quality standards into a model of intra-industry trade with heterogeneous polluters. Pollution stems from consumption and pollution intensity declines with product-specific environmental quality. We formally analyze the effects of environmental standards and trade liberalization on intra-industry trade patterns, pollution, and welfare. Trade liberalization takes the form of lower per-unit trade costs, lower fixed foreign-market entry costs, or greater number of trading partners. When consumer preferences for environmental quality are weak (strong) relative to the environmental quality elasticity of production costs, firms discovering dirtier (cleaner) products are more profitable and engage in exporting. More stringent environmental standards or trade liberalization policies enhance per-capita real consumption. The effects of these policies on global pollution and welfare are ambiguous.

***JEL Classification*:** Q48, Q53 and L91

***Key words*:** intra-industry trade; firm heterogeneity; environmental standards; environmental R&D.

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1. Introduction

The nexus between trade and the environment has generated an intense academic and policy debate.[1] Despite the large body of theoretical and empirical literature, the channels through which international trade influences environmental quality are not well understood. Consider, for instance, the effects of tougher environmental standards on international competitiveness and global pollution. On the one hand, Porter (1991) and Porter and Van der Linde (1995) argue that tough environmental standards trigger environmentally friendly technological innovations that may reduce global pollution and enhance international competitiveness. On the other hand, Palmer et al. (1995), citing survey evidence argue that the costs of environmental regulations exceed their benefits implying that environmental regulations harm international competitiveness.

Similar considerations apply to several other controversial hypotheses concerning the effects of globalization on the environment. According to the "race to the bottom" hypothesis, import competition from countries with low environmental standards puts pressure for less stringent environmental regulations in countries with high environmental standards; the "pollution heaven hypothesis" asserts that countries with low environmental standards become destinations of multinationals using pollution-intensive technologies leading to higher global pollution; and the "gains from trade" hypothesis states that openness encourages growth and innovation both of which could improve environmental quality.

The aforementioned arguments have been developed using traditional static and dynamic trade models generating inter-industry trade based on comparative advantage (Bovenberg and Smulders, 1995; Brock and Taylor, 2005; Chao and Yu. 2007). A few studies have addressed environmental issues in open economies engaging in intra-industry trade generated by symmetric monopolistically competitive firms (Gurtzgen and Rauscher, 2000; Fung and Maechler, 2005; Haupt , 2006;), or multi-country models with trade costs generating Ricardian trade under perfect competition (Erdogan, 2014).

The present paper studies formally the impact of environmental standards and globalization in an economic environment characterized by environmental-quality heterogeneity. It is partially motivated by the global automobile industry which constitutes a major source of air pollution.[2] The global automobile industry features substantial intra-industry trade and product-specific heterogeneity in environmental quality.[3]

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[1] Frankel (2009) offers an excellent overview of the literature addressing the environmental effects of trade.

[2] Emissions, such as air toxics and urban smog, contribute substantially to health and environmental degradation. Additionally, a typical consumer's most polluting daily activity is car driving. On average, each car generates 20 pounds of CO_2 per gallon burned leading to 6 to 9 tons of CO_2 emissions each year. For a typical household in the United States, vehicle emissions contribute to 51% of CO_2, followed by household appliances (26%), and heating and cooling (18%).

[3] Cars with different fuel efficiency deliver different amounts of emissions. For instance, among 2014 models, Chevrolet Spark EV delivers 119 miles per gallon whereas Mercedes-Benz SLS delivers 14 miles per gallon. Many countries including the United States, Japan and Germany export and import cars and trucks from each other. Feenstra and Taylor (2014, Table 6-4) report that in 2012 the value of intra-industry index for small cars was 40 percent.

Environmental standards on vehicle emissions constitute an important national and global policy tool used to improve air quality. These environmental quality standards are expressed as minimum fuel efficiency requirements in the United States or maximum CO_2 emissions in Europe.[4] Finally, the global character of the automobile industry has generated international cooperation leading to a global harmonized emission standard.

Investment in environmental R&D is common in U.S. manufacturing industries and accounts for a sizable share of R&D. Scott (2003) surveys a group of manufacturing companies and reports that, on average, 23.9% of firm R&D expenditures are channeled towards environmental projects. Moreover, over one-half of the firms participating in the survey indicate that environmental R&D projects are undertaken because of specific environmental legislation. Goldberg (1998) confirms this finding by arguing that Corporate Average Fuel Economy Standards (CAFE) regulation offers incentives to develop environmentally friendlier technologies and vehicles.

In this paper we propose a model of intra-industry trade with heterogeneous polluters and structurally symmetric countries to address the following questions. What determines environmental-quality heterogeneity within each industry and the environmental content of intra-industry trade? Do more stringent global environmental standards lower industry productivity and competitiveness? What are the effects of higher environmental standards and trade liberalization on global consumption-based pollution, and welfare?

Following the theory of trade with heterogeneous firms, we envision a global economy consisting of many structurally identical countries with labor as the sole factor of production.[5] We are the first to recognize that the assumption of structurally identical countries is restrictive and excludes the analysis of North-South environmental issues including national differences in emission standards. However, this assumption carries several advantages. First, it offers considerable analytical mileage and sharpens the intuition of main results. Second, the assumption of symmetric countries excludes links between trade and the environment that have been analyzed extensively by other studies: there are no gains from trade based on terms-of-trade changes; there are no cross-country income differences; and there are no incentives for international factor movements. In other words, the assumption of structurally identical countries highlights the environmental effects of firm heterogeneity which is missing from the existing literature on trade and the environment.

In our model, new varieties are discovered through resource-based environmental R&D investment. Firms engage in environmental R&D in response to government regulations with the purpose of meeting the minimum

[4] In 2009, President Barack Obama announced higher emission standards requiring each manufacturer to reach an average of 35.5 miles per gallon (MPG) by 2016. The European Union has adopted the grams per kilometer car emissions standard (EU NEDC). An et al. (2011) provide more details on policies associated with vehicle emissions.

[5] The literature developing the theory of trade with heterogeneous firms includes Melitz (2003), Melitz and Ottaviano (2008), Baldwin and Harrigan (2011), and Johnson (2012) among many others. Redding (2011) provides an excellent literature review of theories of trade with heterogeneous firms.

environmental quality standard.[6] We view environmental R&D as a compulsory investment before any production materializes. We assume that firms pay a fixed entry cost to invest in environmental R&D enabling them to draw an environmental quality parameter from a common and known distribution. Each successful firm learns the environmental quality level and faces an exogenous, government-imposed, minimum environmental-quality standard, such as CO_2 emissions. If the discovered variety does not meet this standard, the firm exits the market immediately. Firms producing products with environmental quality equal or greater than the government imposed standard serve the market. Additionally, we assume that the marginal cost of production increases with the level of environmental quality. For instance, in the case of cars installing lighter materials, high-quality batteries, better electronic components, and using more high-skilled workers raise both fuel efficiency and per-unit production costs.

As in Melitz (2003), successful firms can engage in exporting by paying a fixed foreign-market entry cost and incurring a per-unit trade cost. These assumptions provide an endogenous export cutoff environmental quality level that partitions firms by export status. The government-imposed standard serves the same purpose in the present model as the domestic fixed cost of production in the literature on heterogeneous firms and trade.

As in the case of vehicles and household appliances, consumption generates pollution. The amount of pollution per variety is proportional to the quantity consumed adjusted by the pollution intensity. The latter decreases with variety's environmental quality. In other words, firms that discover products with higher environmental quality exhibit lower pollution intensities. This assumption is consistent with evidence on cars: the 2015 Mitsubishi Mirage with fuel efficiency of 37 MPG emits 238 grams of CO_2 per mile, whereas the 2015 Chevrolet Spark EV (electric) with fuel efficiency of 119 MPG emits close to zero grams of CO_2.[7]

In the model, firms and consumers take aggregate pollution as given. Firms with larger revenues, enjoy greater operating profits, cover fixed and variable trade costs and engage in exporting. This prediction is consistent with evidence that within narrowly defined product categories firms earning larger revenues and profits engage in exporting.[8]

One of our main findings is identifying conditions under which "cleaner" or "dirtier" products are traded. These conditions stem from the *green* elasticity which increases with the intensity of consumer preferences for environmental quality and decreases with the quality elasticity of production costs. The case of cleaner intra-industry trade arises if consumers exhibit strong preferences (relative to costs) for environmental quality leading to a positive green elasticity. Firms producing products with high environmental quality are larger, charge higher

[6] Environmental R&D may reduce the cost of abatement or reduce the amount of polluting inputs used in the production process, as in Bovenberg and Smulders (1995) and Xepapadeas and Zeeuw (1999).

[7] See www.fueleconomy.gov, the official U.S. government source for fuel economy information.

[8] See Tybout (2003) for a survey of early empirical studies documenting that exporting firms are larger and more productive.

prices, earn greater revenues, and export their products; firms discovering products with lower environmental quality charge lower prices, earn lower revenues and serve the domestic market only.

The case of dirty intra-industry trade arises when consumer preferences for environmental quality are weak relative to product costs leading to a negative green elasticity. In this case, firms discovering varieties with low environmental quality charge lower prices, earn higher revenues and profits and export their products. As a result, the model generates “eco-dumping” in the absence of comparative advantage and international capital movements. In other words, the model offers a novel intra-industry version of the “race to the bottom” hypothesis based on self-selection of heterogeneous polluters where cost-leadership (as opposed to environmental quality leadership) confers international competitive advantage to firms producing dirtier and cheaper products.

We also analyze the effects of more stringent environmental quality standards and trade liberalization on per-capita consumption, global pollution and welfare. Trade liberalization takes the form of lower per-unit trade costs, lower fixed costs of entering foreign markets, or more trading partners. Welfare is modeled as the difference between per-capital consumption and global pollution. We establish that a stricter global environmental quality standard or any form of trade liberalization increase per-capita consumption. The intuition behind this result is analogous to the standard intuition provided by the theory of trade with heterogeneous firms: these policies shift resources from environmental R&D and firms serving the domestic markets to exporters. As a result, the measure of varieties available for consumption rises leading to a lower price index and an increase in per-capita real income and per-capita consumption aggregated over all available varieties.

The effects of global environmental standards and trade liberalization on global pollution are ambiguous. As said, these policies raise the number of consumed varieties and lower the average quantity consumed by increasing the intensity of competition. Pollution intensity decreases with environmental quality introducing another factor that lowers pollution. The increase in the measure of consumed varieties raises the extensive margin of pollution whereas the decline in quantity consumed reduces the intensive margin of pollution. As a result, the impact of trade liberalization and global standards on pollution is ambiguous.[9] This ambiguity is inherited in the welfare effects of these policies because welfare depends negatively on global pollution.

The rest of the paper is organized as follows. Section 2 discusses the contribution of our paper to related studies. Section 3 presents elements of the model and describes the steady-state equilibrium. Section 4 studies the effects of a more stringent environmental standard and trade liberalization on global pollution, per-capita

[9] The ambiguity of trade on pollution is reflected in the empirical literature. For instance, Frankel and Rose (2005, p89) state “The case that would give an environmentalist the greater concern is CO_2. The coefficient on openness (measured by value of trade over GDP) is positive and moderately significant” implying that trade openness increases pollution in this case. Roy (2015) using a similar methodology, based on the gravity equation applied to a cross section of countries argues that the elasticity of pollution with respect to intra-industry trade is substantially greater than the elasticity of pollution with respect to trade openness. Specifically, he finds that one percent change in the index of intra-industry trade *reduces* CO_2 emissions by at least 5.9 percent, whereas one percent change in trade openness *increases* CO_2 by up to 0.4 percent.

consumption and welfare. Section 5 concludes. We relegate algebraic details pertaining to proofs of propositions to the Appendix.

2. Related Literature

The present paper complements the theory of trade with heterogeneous firms pioneered by Melitz (2003) by adding two novel features. First, it establishes that in the presence of a binding product quality standard, the separation of firms by export status depends on virtually all model parameters (as opposed to just trade costs and fixed domestic costs). Second, it shows that the effect of higher minimum quality standards and trade liberalization on the component of welfare that does not depend on pollution is beneficial. In other words, in the absence of pollution, higher product-quality standards improve welfare through similar channels to those triggered by trade liberalization.

The identification of conditions that result in clean or dirty intra-industry trade contributes to two strands of literature. First, the case of clean intra-industry trade is consistent with the Porter Hypothesis that relates stricter environmental standards and to international competitiveness (see Popp (2005) and Xepapadeas and de Zeeuw (1999), among others). A recent study of the European Automobile industry by Miravete, Moral and Thurk (2014) shows that the emissions policy employed by European regulators not only promoted the diffusion of diesel vehicles, but also increased the profitability of domestic manufactures by providing European automakers a comparative advantage. Using standard business terminology, the case of a positive green elasticity in our model corresponds to exploitation of competitive advantage based on benefit leadership.

Second, our paper contributes to the debate on “pollution havens” and “pollution dumping”, one version of which states that countries with low environmental standards or comparative advantage in pollution-intensive goods produce dirty goods which are exported to countries with higher environmental standards, or comparative advantage in cleaner goods (Frankel and Rose, 2005; Frankel, 2009). Our model identifies an intra-industry trade based mechanism of pollution dumping which is independent of national differences in environmental standards, factor endowments, or movements of capital to countries with low environmental standards. In our model, in the case of weak preferences for environmental quality, firms that produce cheaper and dirtier products export them abroad in an environment of identical countries and a binding global environmental quality standard. These firms earn higher profits than average industry profits (competitive advantage) in a global economy with symmetric countries in the absence of comparative advantage and differences in national environmental standards.

Finally our paper complements Kreickemeier and Richter (2014) who propose a model of a small open economy populated by heterogeneous firms differing in productivity (as opposed to product quality) to study the effects of intra-industry trade on production-generated pollution. In contrast, our model focuses on consumption-generated pollution, a global economy characterized by many countries, and the effect of minimum environmental quality standards. As a result, we generate conditions leading to dirty or clean intra-industry trade and take into account the effects of policies on the measure of imported and consumed varieties. These features are absent from their model.

3. The Model

Following the theory of trade with heterogeneous firms, we analyze a global economy consisting of $n+1$ structurally identical countries with $n \geq 1$. As said, the assumption of structurally identical countries is admittedly restrictive but necessary to solve the model. This assumption, which enhances the analysis and sharpens the intuition, has been employed by a large number of studies including the pioneering article by Melitz (2003). It highlights the effects of environmental standards on heterogeneous polluters in the absence of comparative-advantage, international factor mobility, and income differences across countries.

Each country consists of a sole industry producing differentiated goods with labor being the only factor of production. The aggregate supply of labor in each country, denoted by L, is fixed and remains constant over time.

3.1. Consumers

The preferences of a representative consumer are given by

$$U = Q - Z. \tag{1}$$

Variable Q denotes per-capita consumption aggregated over a continuum of products and is defined by the following Dixit and Stiglitz (1977) sub-utility function

$$Q = \left[\int_{\omega \in \Omega} \left[\lambda(\omega)^{\alpha} \frac{q(\omega)}{L} \right]^{\rho} d\omega \right]^{1/\rho}. \tag{2}$$

In Eq.(2), each variety is indexed by ω and Ω denotes the set of all varieties consumed in a typical country. Parameter $0 < \rho < 1$ implies that the constant elasticity of substitution between any two varieties or brands is $\sigma = 1/(1-\rho) > 1$. Variable $q(\omega)$ denotes aggregate consumption of brand ω, and $\lambda(\omega) > 1$ denotes its time-invariant environmental quality.

Motivated by the automobile industry, we consider environmental quality as closely related to the fuel-efficiency of different vehicles as in the US CAFÉ standard. For example, an electric vehicle is associated with a large value of $\lambda(\omega)$ whereas a standard SUV commands a low value of $\lambda(\omega)$. Parameter $\alpha > 0$ is the constant elasticity of consumer's sub-utility with respect to environmental quality $\lambda(\omega)$ and measures the intensity of consumer preferences for environmental quality.[10] A larger value of α implies higher perceived environmental quality and greater consumer willingness to pay for each variety.

Consumption generates pollution. The following function defines aggregate pollution (summed over all varieties consumed in a country)

$$Z = \int_{\omega\in\Omega} z(\omega) d\omega, \tag{3}$$

where $z(\omega)$ is the amount of pollution per variety consumed and given by

$$z(\omega) = \varepsilon q(\omega) / \lambda(\omega). \tag{4}$$

Pollution per variety $z(\omega)$ is directly proportional to consumed quantity $q(\omega)$; and pollution intensity per variety $\varepsilon / \lambda(\omega)$ is inversely related to variety-specific environmental quality. Parameter $\varepsilon \geq 0$ is common among all varieties with higher values of ε implying higher pollution intensity; whereas higher values of environmental quality $\lambda(\omega)$ imply lower pollution intensity. Where $\varepsilon = 0$, consumption does not generate any pollution and the model is equivalent to a model of trade with quality heterogeneity.

Consuming varieties with higher environmental quality increases welfare through two distinct channels: it raises utility directly (analogous to a higher product quality); and reduces pollution intensity resulting in a cleaner environment. Based on the literature on trade and the environment, we model the second channel as an externality: the representative consumer behaves as though her own behavior does not affect aggregate pollution. Note that the assumption of symmetric countries implies that the level of global pollution is equal to the exogenous number of countries times the level of national pollution. As a result, issues associated with transboundary pollution do not arise in the present model.

Each consumer maximizes utility (1) taking aggregate pollution Z as given, subject to the budget constraint $\int_{\omega\in\Omega} p(\omega)[q(\omega)/L] d\omega = E,$ where $p(\omega)$ is the market price; E is per-capita consumer expenditure, and L is the number of consumers in a typical country. This maximization problem yields the market quantity demanded $q(\omega)$ and expenditure $r(\omega) = p(\omega)q(\omega)$ for variety ω

$$q(\omega) = ELP^{\sigma-1} p(\omega)^{-\sigma} \lambda(\omega)^{\alpha(\sigma-1)}; \qquad r(\omega) = ELP^{\sigma-1} p(\omega)^{1-\sigma} \lambda(\omega)^{\alpha(\sigma-1)}. \tag{5}$$

[10] According to a 2014 survey by the Consumer Reports National Research Center, quality, safety, performance, value and fuel economy are the most important considerations for today's new-car buyers. Consumers are willing to pay higher prices and even submit to a waiting list to purchase environmentally friendly electric and hybrid vehicles.

Variable P is now defined as *the green price index*, that is, the standard price index adjusted for environmental quality

$$P = \left[\int_{\omega \in \Omega} \left(\frac{p(\omega)}{\lambda(\omega)^{\alpha}} \right)^{1-\sigma} d\omega \right]^{1/(1-\sigma)} . \tag{6}$$

Where consumers do not care about environmentally friendly products ($\alpha = 0$), the green price index equals the standard aggregate price index, as in Melitz (2003). Firm revenue $r(\omega)$ decreases with price because each firm faces an elastic demand curve. However, for any price level, greener products enjoy greater demand and revenues reflecting consumer demand for environmental quality.

Term $\lambda(\omega)^{\alpha} / p(\omega)$ captures the *effective* environmental quality of variety ω and will play a pivotal role in the determination of intra-industry trade. The numerator describes the consumer valuation of environmental quality (perceived benefit) and thus the effective environmental quality is simply per-dollar perceived environmental quality. In other words, consumer demand for a variety with environmental quality $\lambda(\omega)$ depends on the effective environmental quality $\lambda(\omega)^{\alpha} / p(\omega)$.

3.2. Workers and Firms

As said, labor is the sole factor of production with each worker supplying one unit of labor. As a result, labor supply is inelastic and equal to the number of consumers L. There is a continuum of firms with each firm choosing to produce a different variety. In each country the government sets the (global) environmental quality standard, which is denoted with $\bar{\lambda}$. Firms must invest in environmental R&D to discover new varieties. Each potential entrant incurs a fixed entry cost $f_e > 0$, measured in units of labor, and interpreted as the number of R&D researchers required to discover a new variety. After incurring the said fixed cost, a firm discovers a new variety ω and the embedded environmental quality by drawing parameter $\lambda(\omega)$ from a general and commonly known distribution with positive support.

After drawing its environmental quality, a firm has to decide whether to enter the domestic and foreign markets based on government regulations and profitability considerations. If the environmental quality of a newly discovered variety does not meet the global (and national) environmental standard ($\lambda(\omega) < \bar{\lambda}$), the firm exits the market. If the new product meets the environmental standard ($\bar{\lambda} \leq \lambda(\omega)$), the firm manufactures the product without incurring any fixed production costs. We assume that the environmental standard is strictly enforced and abstract from compliance issues stemming from firm attempts to conceal the true value of environmental quality.[11]

Manufacturing of variety ω entails marginal (and average) costs that increase with environmental quality. In order to produce $q(\omega)$ units of output, $l(\omega)=\lambda(\omega)^{\gamma}q(\omega)$ units of labor are required, where $\gamma>0$ is the constant elasticity of unit-labor requirement with respect to environmental quality. Thus each firm faces constant marginal and average costs $\lambda(\omega)^{\gamma}w$, where w denotes the wage rate. For example, we adopt the reasonable assumption that, all else equal, resources (and costs) required to produce an electric Nissan Leaf delivering 114 MPGe exceed resources needed to manufacture a Honda Civic delivering 35 MPG. For the remainder of this paper, we omit index ω and use the environmental quality parameter λ to denote a particular variety when this practice does not create notational ambiguity.

Firms meeting the environmental standard $\bar{\lambda}$ serve the domestic market but face additional costs to enter each foreign market. Entry into a foreign market requires per-period fixed costs $f_x>0$ measured in units of labor and per-unit trade cost $\tau>1$. The latter is modeled in the usual iceberg fashion: τ units must be produced in the country of origin in order for one unit to arrive in the destination country. Exporting costs are independent of environmental quality λ.

Regardless of differences in environmental quality, each firm faces a constant elasticity demand curve, as per Eq. (5). A firm serving the domestic market maximizes profits by taking the measure of varieties consumed Ω and green price index P as given. Standard calculations deliver the following pricing rules. A firm with environmental quality λ sets its domestic price $p_d(\lambda)$ and export price $p_x(\lambda)$ in each foreign market as a constant markup over marginal cost

$$p_d(\lambda)=\lambda^{\gamma}/\rho; \quad p_x(\lambda)=\tau\lambda^{\gamma}/\rho, \tag{7}$$

where we set the wage rate equal unity ($w\equiv 1$) in Eq. (7) by choosing labor as the numeraire. A firm with environmental quality λ faces greater marginal costs $\tau\lambda^{\gamma}$ when serving a foreign market as opposed to serving the domestic market because $\tau>1$. Firms producing goods with higher environmental quality charge higher prices.[12]

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[11] In September 2015, the German automaker Volkswagen was issued a notice of violation by the US EPA after it became known that the company had equipped vehicles powered by turbocharged direct injection diesel engines with software programming that activated the nitrogen oxides emissions controls only during laboratory emissions testing. This reduced the emission levels during testing below the emission levels during actual driving. Volkswagen announced plans to spend more than $7 billion on fixing these emission violations.

[12] Eq. (5) implies that each firm faces a marginal revenue function $MR=p(1-1/\sigma)=p\rho$ which declines with quantity, because $\partial p/\partial q<0$, and constant domestic and foreign marginal costs: $MC=\lambda^{\gamma}$ and $MC=\tau\lambda^{\gamma}$, respectively. Setting marginal revenue equal to marginal cost in each market delivers Eq. (7). The downward sloping marginal revenue function and constant marginal costs features ensure that the second-order conditions for profit maximization hold.

The consumer willingness to pay and the market price depend on environmental quality. The green elasticity reflects this dependence.

Definition 1: *Let* $\Lambda(\lambda)=\lambda^{\alpha}/p(\lambda)$ *denote the market effective environmental quality, where the profit-maximizing price* $p(\lambda)$ *is given by Eq.* (7). *The* ***green elasticity*** $\phi \equiv \partial \ln \Lambda(\lambda)/\partial \ln \lambda = a-\gamma$ *denotes the percentage change in effective environmental quality* $\Lambda(\lambda)$ *brought about by one percent change in actual environmental quality* λ.

In the present model, the green elasticity ϕ is constant. When ϕ is positive (negative), the effective environmental quality increases (decreases) with actual environmental quality. This property has implications for the pattern of intra-industry trade.

The quantities of a variety with environmental quality λ sold in the domestic and each of n foreign markets are given by

$$q_d(\lambda)=ELP^{\sigma-1}\rho^{\sigma}\lambda^{\alpha(\sigma-1)-\gamma\sigma}; \qquad q_x(\lambda)=\tau^{-\sigma}ELP^{\sigma-1}\rho^{\sigma}\lambda^{\alpha(\sigma-1)-\gamma\sigma}. \tag{8}$$

Total quantity $q(\lambda)$ produced by a firm depends on export status. A firm serving only the domestic market produces

$$q(\lambda)=q_d(\lambda)=ELP^{\sigma-1}\rho^{\sigma}\lambda^{\alpha(\sigma-1)-\gamma\sigma}, \tag{9}$$

whereas each exporter produces

$$q(\lambda)=q_d(\lambda)+nq_x(\lambda)=(1+n\tau^{-\sigma})q_d(\lambda)=(1+n\tau^{-\sigma})ELP^{\sigma-1}\rho^{\sigma}\lambda^{\alpha(\sigma-1)-\gamma\sigma}. \tag{10}$$

Domestic revenue $r_d(\lambda)=p_d(\lambda)q_d(\lambda)$ and revenue in each of n foreign markets $r_x(\lambda)=p_x(\lambda)q_x(\lambda)$ are given by

$$r_d(\lambda)=EL(P\rho)^{\sigma-1}\lambda^{\phi(\sigma-1)}; \qquad r_x(\lambda)=\tau^{1-\sigma}r_d(\lambda)=\tau^{1-\sigma}EL(P\rho)^{\sigma-1}\lambda^{\phi(\sigma-1)}. \tag{11}$$

Firm revenue depends on export status as well and given by

$$r(\lambda)=r_d(\lambda)+I_x n r_x(\lambda)=(1+I_x n\tau^{1-\sigma})r_d(\lambda)=(1+I_x n\tau^{1-\sigma})EL(P\rho)^{\sigma-1}\lambda^{\psi}, \tag{12}$$

where I_x is the indicator function which equals one if the firm engages in exporting and zero if the firm serves only the domestic market; and

$$\psi=(\alpha-\gamma)(\sigma-1)=\phi(\sigma-1) \tag{13}$$

denotes the environmental-quality elasticity of firm revenue.

Eq. (12) reveals that the green elasticity regulates the dependence of firm revenue (and operating profits) on environmental quality. Specifically, the elasticity of revenue with respect to environmental quality $\psi=\partial \ln r(\lambda)/\partial \ln \lambda$ is constant and equal to $\phi(\sigma-1)$, where $\sigma=1/(1-\rho)>1$ is the elasticity of substitution between two varieties and the price elasticity of demand for each variety. As a result, the sign of green elasticity $\phi = \alpha - \gamma$ is the same as the sign of $\partial \ln r(\lambda) / \partial \ln \lambda$. The intuition behind this property is as follows. Eq. (5) indicates that an increase in environmental quantity raises the quantity demanded and firm revenue for any given price. However, the effect of environmental quality on the optimal firm revenue is ambiguous: first, for a given price, an increase in λ by one percent raises firm revenue directly by $\alpha(\sigma - 1)$ percentage points; second, one-percent increase in λ raises the profit-maximizing price by γ percentage points (see Eq. (7)) and thus lowers firm revenue by $\gamma(\sigma - 1)$ percentage points because each firm faces an elastic demand curve. Consequently, the overall effect of environmental quality on firm revenue is ambiguous and depends on green elasticity $\phi = \alpha - \gamma$. If $\alpha > \gamma$, where consumers have a strong preference for environmental quality, the green elasticity is positive and cleaner, more expensive products enjoy larger revenues. If $\gamma > \alpha$, where consumers care more about the costs of environmental quality, the green elasticity is negative and dirtier, cheaper products enjoy larger revenues.

We continue the analysis by stating the properties of profit flows. Standard calculations imply that domestic profits and profits from exporting are proportional to corresponding revenues. Specifically, for a firm which meets the global environmental standard ($\bar{\lambda} \leq \lambda$), domestic profit flow $\pi_d(\lambda)$ is given by

$$\pi_d(\lambda) = r_d(\lambda) / \sigma, \tag{14}$$

and profit flow $\pi_x(\lambda)$ earned from sales in each of n foreign markets is

$$\pi_x(\lambda) = \left[r_x(\lambda) / \sigma \right] - f_x, \tag{15}$$

where f_x is the fixed cost of foreign-market entry. As a result, total per-period profit $\pi(\lambda)$ is given by

$$\pi(\lambda) = \pi_d(\lambda) + I_x n \pi_x(\lambda), \tag{16}$$

where I_x assumes the value of zero if the firm serves the domestic market only and the value of one if the firm serves all export markets. The following lemma summarizes the basic findings so far.

Lemma 1: *Active firms charge prices which increase with environmental quality. If the green elasticity ϕ is positive, then firms discovering products with higher environmental quality earn larger revenues and profit flows. If the green elasticity ϕ is negative, then firms discovering products with lower environmental quality earn larger revenues and profit flows.*

Since exporting involves fixed costs, only the larger and most profitable firms meeting the global environmental standard serve all foreign markets. Lemma 1 states that the green elasticity ϕ determines the environmental content of intra-industry trade, as will be discussed later.

The amount of pollution $z(\lambda)$ emitted by a firm depends on export status as well. A firm discovering a product with environmental quality λ emits

$$z(\lambda) = z_d(\lambda) + I_x n z_x(\lambda) = (1 + I_x n\tau^{-\sigma}) z_d(\lambda) = (1 + I_x n\tau^{-\sigma})\varepsilon ELP^{\sigma-1}\rho^{\sigma}\lambda^{\phi(\sigma-1)-(\gamma+1)}, \tag{17}$$

where I_x is the export-status indicator function. The effect of environmental quality on pollution per variety is in general ambiguous. An increase in quality reduces pollution directly, as indicated by Eq.(4), but has an ambiguous effect on quantity consumed $q(\omega)$, as established by Eq. (10). Thus, if the green elasticity is negative firms with higher quality produce less and generate less pollution. If the green elasticity is positive and sufficiently high, then firms with greener products produce more units than firms with dirtier products and thus contribute to pollution more.

3.3. *Entry Decisions*

Following the pioneering work of Melitz (2003), suppose that in each country there are large numbers of prospective ex-ante identical entrants. A firm engaged in environmental R&D incurs fixed entry cost $f_e > 0$. This initial cost allows it to draw its environmental quality parameter λ from a common and known distribution $g(\lambda)$ with positive support over $(0,\infty)$ and with continuous cumulative distribution $G(\lambda)$. After observing its environmental quality level, each firm decides whether to exit the market immediately or start producing. Countries are identical and thus every country sets the same environmental standard, expressed as a minimum environmental quality level $\bar{\lambda} > 1$. The global standard is strictly enforced and serves as the domestic cutoff quality (productivity) level in the theory of heterogeneous firms. If a firm discovers a product with environmental quality $\lambda < \bar{\lambda}$, then the government does not allow it to enter the market. If a firm discovers a product with environmental quality equal to or greater than the standard $\lambda \geq \bar{\lambda}$, then it is allowed to enter the market and thus earns positive operating (and total) profits.

After learning its environmental quality level λ, a firm must decide whether or not to export by incurring a fixed export cost $f_x > 0$ and a per-unit trade cost $\tau > 1$. The export cutoff level of environmental quality λ_x is determined implicitly by setting the flow of profits from exporting equal to zero

$$\pi_x(\lambda_x) = [r_x(\lambda_x)/\sigma] - f_x = 0 \quad \Leftrightarrow \quad r_x(\lambda_x) = \sigma f_x. \tag{18}$$

Firms earning positive profits from exporting ($\pi_x(\lambda) \geq 0$ or $r_x(\lambda) \geq \sigma f_x$) serve all foreign markets. However, whether firms producing greener or dirtier products become exporters depends on the sign of green elasticity as stated in Lemma 1.

The following proposition summarizes our findings regarding the environmental pattern of intra-industry trade.

Proposition 1: *Firms with higher environmental quality products ($\bar{\lambda} \leq \lambda$) incur higher marginal costs and charge higher prices. The pattern of intra-industry trade depends on green elasticity $\phi = \alpha - \gamma$ as follows:*

(i) *If the green elasticity is positive ($\phi > 0$) and firms face sufficiently high foreign-entry market costs f_x, then the export cutoff environmental quality level is strictly greater than the global environmental standard ($\bar{\lambda} < \lambda_x$); firms producing products with low environmental quality λ such as $\bar{\lambda} \leq \lambda < \lambda_x$ earn lower profits and serve only their domestic market; and firms producing products with high environmental quality λ such as $\lambda_x < \lambda$ earn higher profits and serve their domestic and all foreign markets.*

(ii) *If the green elasticity is negative ($\phi < 0$) and firms incur sufficiently low foreign-market entry costs f_x, then the export cutoff environmental quality level is strictly greater than the global environmental standard ($\bar{\lambda} < \lambda_x$); firms producing varieties with low environmental quality λ such as $\bar{\lambda} \leq \lambda < \lambda_x$ earn higher profits and serve their domestic and foreign markets; and firms producing varieties with high environmental quality λ such as $\lambda_x < \lambda$ earn lower profits and serve only their domestic market.*

Proof: Please see the Appendix.

Proposition 1 highlights the role of green elasticity in determining the environmental pattern of intra-industry trade. In the case of positive green elasticity and sufficiently high trade costs, firm global competitive advantage stems from benefit (as opposed to cost) leadership. Consumers have strong preferences for environmental quality, and thus firms with cleaner, more expensive products earn higher profits, incur both fixed and variable trade costs and export their products. Firms discovering dirtier products, charge lower prices and serve only the domestic market because they cannot pay the high trade costs of entering and serving foreign markets.

In contrast, when the green elasticity is negative and trade costs sufficiently low, the model generates dirty intra-industry trade. In this case, consumers care more about costs than perceived environmental benefits, generating favorable conditions for cost (as opposed) to benefit leadership as a strategy to achieve global competitive advantage. Consequently, firms discovering products with low environmental quality charge lower prices and enjoy higher operating profits, whereas firms discovering cleaner products charge higher prices and earn lower profits. The latter cannot cover the cost of exporting and serve the domestic market only. As a result, for sufficiently low trade costs, a negative green elasticity generates dirty intra-industry trade. In other words, when the green elasticity is negative, the model generates intra-industry "eco-dumping" where the environmental content of trade is lower than the environmental content of good produced by firms serving the domestic market only.

Where the green elasticity is zero (that is, $\alpha = \gamma$), profit-maximizing revenues (and profit flows) are independent of environmental quality. In this special "razor's edge" case, all firms export their products for a sufficiently low value of the global environmental standard; whereas, for a sufficiently high value of the global environmental standard, all firms serve their domestic markets only. This implication is unrealistic and inconsistent with empirical studies asserting that some firms export and others serve only their domestic markets within narrowly defined product categories. We therefore focus on $\alpha \neq \gamma$ and analyze the cases of clean and dirty intra-industry trade.

Proposition 1 generates the partition of firms into exporters and non-exporters which depends on per-capita expenditure E and the green price index P . These variables are endogenous. This means that the previous discussion relating the pattern of intra-industry to the sign of green elasticity does not take into account firm-entry considerations. In Section 2.6, we will describe the steady-state equilibrium conditions and establish the general-equilibrium validity of Proposition 1.

Next, we analyze the entry decision of a typical firm. Every incumbent firm faces a constant probability of default ($0 < \delta < 1$) in each period caused by a stochastic shock. In the present context, this stochastic shock can be interpreted as changing tastes that eliminate the demand for a particular variety. Since firm default is uncorrelated with environmental quality, the exit process is independent of the distribution of the latter. The probability of drawing an environmental quality level λ is governed by density function $g(\lambda)$. As a result, the ex-ante probability of successful entry is given by $p_{in} = 1 - G(\bar{\lambda})$. The density of the distribution of environmental quality draws meeting the environmental standard, which is denoted by $\mu(\lambda)$, is the conditional density of $g(\lambda)$ on the interval $\left[\bar{\lambda}, \infty\right)$ defined by

$$\mu(\lambda) = \frac{g(\lambda)}{1 - G(\bar{\lambda})}. \tag{19}$$

The ex-ante probability that an incumbent firm becomes an exporter equal the fraction of exporters and is given by

$$p_x = \frac{1 - G(\lambda_x)}{1 - G(\bar{\lambda})}. \tag{20}$$

3.4. Aggregation

Aggregation provides expressions for various components of ex-ante profits that are needed to establish the general-equilibrium properties of the model. Let M_p denote the measure of varieties produced, M_x the measure of exported varieties, and M_c the measure of varieties available for consumption in each country. These measures are related to each other as follows.

$$M_x = p_x M_p; \quad M_c = M_p + nM_x = (1+np_x)M_p. \tag{21}$$

Let $\tilde{\lambda}_p$ denote an index of environmental quality of domestically produced goods. This quality index is defined by

$$\tilde{\lambda}_p = \tilde{\lambda}(\bar{\lambda}) = \left[\frac{1}{1-G(\bar{\lambda})}\int_{\bar{\lambda}}^{\infty} \lambda^{\psi} g(\lambda)d\lambda\right]^{\frac{1}{\psi}}, \tag{22}$$

where $\psi = \phi(\sigma-1) \neq 0$ is the quality elasticity of firm revenue defined in Eq. (13). Because $\sigma > 1$, if the green elasticity is positive ($\phi, \psi > 0$), then $\tilde{\lambda}_p$ has identical properties to those associated with the average firm productivity in Melitz (2003). If the green elasticity is negative ($\phi, \psi < 0$), then $\tilde{\lambda}_p$ corresponds to the weighted harmonic mean of effective qualities of all domestically produced varieties, as in Dinopoulos and Unel (2013). The quality index $\tilde{\lambda}_p$ depends on the global environmental standard $\bar{\lambda}$ and density $g(\lambda)$ of environmental quality.

Let $\tilde{\lambda}_x$ denote the average environmental quality of exports, which is defined by

$$\tilde{\lambda}_x = \tilde{\lambda}(\lambda_x) = \left[\frac{1}{1-G(\lambda_x)}\int_{\lambda_x}^{\infty} \lambda^{\psi} g(\lambda)d\lambda\right]^{\frac{1}{\psi}}. \tag{23}$$

The average environmental quality of varieties available for consumption in a country is denoted with $\tilde{\lambda}_c$ and defined by

$$\tilde{\lambda}_c = \left[\frac{M_p}{M_c}\tilde{\lambda}_p^{\psi} + \frac{nM_x}{M_c}\tau^{1-\sigma}\tilde{\lambda}_x^{\psi}\right]^{\frac{1}{\psi}}. \tag{24}$$

The first term inside the square brackets corresponds to domestically produced varieties and the second term corresponds to imported varieties.

Lemma 2: *The average environmental quality of produced varieties $\tilde{\lambda}_p$ is strictly greater and increases with the environmental standard ($\tilde{\lambda}_p > \bar{\lambda}$ and $\partial\tilde{\lambda}_p / \partial\bar{\lambda} > 0$). If the green elasticity is positive ($\phi > 0$), then the average environmental quality of exports $\tilde{\lambda}_x$ is strictly greater and increases with the export cutoff environmental quality*

($\tilde{\lambda}_x > \lambda_x$ and $\partial\tilde{\lambda}_x / \partial\lambda_x > 0$). If the green elasticity is negative ($\phi < 0$), then the average environmental quality of exports $\tilde{\lambda}_x$ is strictly smaller and decreases with the export cutoff environmental quality ($\tilde{\lambda}_x < \lambda_x$ and $\partial\tilde{\lambda}_x / \partial\lambda_x < 0$).

Proof: Please see the Appendix.

Green price index P, aggregate revenue R and aggregate quantity Q in any country may be written as functions of the average level of environmental quality $\tilde{\lambda}_c$ and the measure of varieties available for consumption M_c. The Appendix provides algebraic details.

$$P = M_c^{1/(1-\sigma)} \tilde{\lambda}_c^{\gamma-\alpha} / \rho; \quad R = M_c r_d(\tilde{\lambda}_c); \quad Q = \rho M_c^{1/(\sigma-1)} \tilde{\lambda}_c^{\alpha-\gamma} \quad . \tag{25}$$

The market equilibrium in any country is isomorphic to the equilibrium with M_c identical firms, each of which produces a variety with environmental quality $\tilde{\lambda}_c$.

Finally, expected revenue $\bar{r}$ and profit $\bar{\pi}$ earned by a representative firm serving the domestic and foreign markets are given by

$$\bar{r} = r_d(\tilde{\lambda}_p) + p_x n r_x(\tilde{\lambda}_x); \qquad \bar{\pi} = \pi_d(\tilde{\lambda}_p) + p_x n \pi_x(\tilde{\lambda}_x). \tag{26}$$

3.5. Free Entry

A firm producing a variety with environmental quality λ earns operating profit $\pi(\lambda)$ and faces a constant probability of death δ in each period. Following the literature on trade with heterogeneous firms, we assume that the discount (and interest) rate equals zero. As a result, firm market value is given by

$$v(\lambda) = \max\left\{0, \sum_{t=0}^{\infty} (1-\delta)^t \pi(\lambda)\right\} = \max\left\{0, \frac{\pi(\lambda)}{\delta}\right\}, \tag{27}$$

where the second equality is based on the property that environmental quality is time invariant and thus the firm earns the same profit flow each period. The firm meets the environmental standard and enters the market successfully with probability $1 - G(\bar{\lambda})$. As a result, expected net benefits of conducting environmental R&D are equal to ex-ante expected firm value $\left[1 - G(\bar{\lambda})\right]\bar{v}$, where $\bar{v} = \bar{\pi} / \delta$ is the (ex-post) value of a successful entrant, and $\bar{\pi}$ is the profit flow $\bar{\pi} = \pi_d(\tilde{\lambda}_p) + p_x n \pi_x(\tilde{\lambda}_x)$, defined in Eq. (26).

Free entry into environmental R&D leads to zero expected net benefits: expected benefits of entry $\left[1-G(\bar{\lambda})\right]\bar{v}$ must equal the fixed R&D entry cost f_e yielding the free-entry condition

$$\delta f_e = \left[1-G(\bar{\lambda})\right]\bar{\pi}. \tag{28}$$

The LHS of Eq. (28) is expected cost of environmental R&D and its RHS is average firm profit. Average firm profit $\bar{\pi}$ is therefore determined by firm default rate δ, fixed cost of environmental R&D f_e, and the global environmental standard $\bar{\lambda}$. Ceteris paribus, a higher environmental standard $\bar{\lambda}$ lowers the probability of successful entry $1-G(\bar{\lambda})$ and requires higher profit flow $\bar{\pi}$ to restore free-entry condition(28). Similar considerations apply to the rate of default δ and entry cost f_e: higher expected R&D cost δf_e requires higher profit flow $\bar{\pi}$.

3.6. *Equilibrium*

At the steady-state equilibrium, the zero-profit condition(18), determines the relationship between the average profit per firm $\bar{\pi}$ and the export cutoff environmental quality λ_x.

Combining Eq. (11) and Eq. (14) yields

$$\frac{\pi_d(\tilde{\lambda}_p)}{\pi_d(\lambda_x)} = \frac{r_d(\tilde{\lambda}_p)}{r_d(\lambda_x)} = \left(\frac{\tilde{\lambda}_p}{\lambda_x}\right)^{\psi}; \qquad \frac{r_x(\tilde{\lambda}_x)}{r_x(\lambda_x)} = \left(\frac{\tilde{\lambda}_x}{\lambda_x}\right)^{\psi}. \tag{29}$$

We can express the average profit flow $\bar{\pi}$, which is defined by Eq. (26), as

$$\bar{\pi} = \tau^{\sigma-1} f_x \left(\frac{\tilde{\lambda}_p}{\lambda_x}\right)^{\psi} + n f_x \left(\frac{1-G(\lambda_x)}{1-G(\bar{\lambda})}\right)\left[\left(\frac{\tilde{\lambda}_x}{\lambda_x}\right)^{\psi} - 1\right], \tag{30}$$

where $\tilde{\lambda}_x$ is a function of λ_x.[13] Substituting Eq. (30) into Eq. (28) yields the following zero-profit *environmental R&D condition*

$$\delta f_e / f_x = F(\lambda_x), \tag{31}$$

where

$$F(\lambda_x) = \lambda_x^{-\psi}\left\{\tau^{\sigma-1}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi} g(\lambda)d\lambda + n\left[\int_{\lambda_x}^{\infty}\lambda^{\psi} g(\lambda)d\lambda - [1-G(\lambda_x)]\lambda_x^{\psi}\right]\right\}. \tag{32}$$

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[13] The first and second terms in the right-hand-side (RHS) of (30) are equal to the corresponding terms in the RHS of $\bar{\pi}$ in (26). Eq. (11) and Eq. (18) imply $\pi_d(\lambda_x) = \tau^{\sigma-1} r_x(\lambda_x)/\sigma = f_x \tau^{\sigma-1}$. Substituting $\pi_d(\lambda_x)$ in Eq. (29) yields the first term in the RHS of Eq. (30). Eq. (15) implies $\pi_x(\tilde{\lambda}_x) = \sigma^{-1} r_x(\tilde{\lambda}_x) - f_x$. Substituting $r_x(\tilde{\lambda}_x)$ from Eq. (29), $p_x = [1-G(\lambda_x)]/[1-G(\bar{\lambda})]$ and $r_x(\lambda_x) = \sigma f_x$ from Eq. (18) delivers to the second term in the RHS of Eq. (30).

The environmental R&D condition determines the general-equilibrium export cutoff level λ_x. The LHS of Eq. (32) equals per-period expected fixed environmental R&D costs expressed in units of foreign-market entry cost f_x; and $F(\lambda_x)$ equals per-period expected profits, expressed in units of foreign-market entry costs f_x, earned by a firm engaged in environmental R&D. It can be easily established that expected profits decrease monotonically with export cutoff quality level λ_x *if and only if* the green elasticity ϕ is positive: $\partial F / \partial \lambda_x < 0 \Leftrightarrow \phi > 0$.[14]

The intuition behind the sign of $F(\lambda_x)$ is as follows. Observe that per-period firm profit is higher for firms serving both the domestic and foreign markets than for firms serving only their domestic markets, as indicated by Proposition 1. In the case of positive green elasticity, firms producing products with environmental quality higher than the export cutoff level ($\lambda > \lambda_x$) become exporters and earn higher profits. In this case, an increase in λ_x reduces the likelihood that a firm will earn higher profits by becoming an exporter and increases the likelihood that the firm will earn lower profits by serving the domestic market only. As a result, if $\phi > 0$, then an increase in λ_x reduces per-period expected (average) profits $F(\lambda_x)$. If $\phi < 0$, then firms producing products with environmental quality λ which is lower than the export cutoff level λ_x earn higher profits and become exporters. In this case, an increase in λ_x increases the range of environmental quality generating higher profits and reduces the likelihood of lower profits associated with serving only the domestic market. As a result, if $\phi < 0$ then an increase in λ_x raises per-period average firm profit $F(\lambda_x)$.

The environmental R&D condition $\delta f_e / f_x = F(\lambda_x)$ determines the export cutoff level as follows. Consider first the case of $\phi > 0$, where $F(\lambda_x)$ decreases with λ_x. The R&D condition must hold at the minimum environmental standard, ($\delta f_e / f_x = F(\bar{\lambda})$). Thus if $\lambda_x = \bar{\lambda}$, then all active firms export and obtain maximum expected profits equal to $F(\bar{\lambda})$. If $\delta f_e / f_x = F(\lambda_x) < F(\bar{\lambda})$, then the export cutoff level is higher than the global environmental standard ($\lambda_x > \bar{\lambda}$); firms discovering environmental quality products exceeding the export cutoff ($\lambda > \lambda_x$) become exporters; and firms with environmental quality products below the export cutoff level and above the global environmental standard ($\bar{\lambda} \le \lambda < \lambda_x$) serve their domestic market only.

Similar reasoning applies to the case of negative green elasticity. In this case, evaluating the R&D condition at the global standard where $\lambda_x = \bar{\lambda}$ implies that all firms obtain minimum ex ante profit equal to

[14] Formally, the partial derivative of the RHS of Eq. (32) with respect to λ_x equals $\partial F(\lambda_x) / \partial \lambda_x = -\phi \lambda_x^{-(\phi+1)} \left\{ \tau^{\sigma-1} \int_{\bar{\lambda}}^{\infty} \lambda^{\phi} g(\lambda) d\lambda + n \int_{\lambda_x}^{\infty} \lambda^{\phi} g(\lambda) d\lambda \right\}$ implying that *sign* $(\partial F / \partial \lambda_x) = sign(-\phi)$.

$F(\bar{\lambda},\bar{\lambda})$. In this case, all firms serve the domestic market and there is not separation between local firms and exporters. Since expected profit increases with λ_x in this case, if $F(\bar{\lambda}) < \delta f_e / f_x = F(\lambda_x)$ (that is, for sufficiently high expected entry costs $\delta f_e / f_x$), the export cutoff level is strictly greater than the global standard ($\lambda_x > \bar{\lambda}$). Firms with environmental quality products higher than the export cutoff ($\lambda > \lambda_x$) serve the domestic market; and firms discovering products with environmental quality between the export cutoff level and the global standard ($\bar{\lambda} \le \lambda < \lambda_x$) engage in exporting.

Fig. 1 illustrates the general-equilibrium solution to the export cutoff level λ_x in the case of positive green elasticity by plotting the LHS and RHS of the environmental (zero-profit) R&D condition (31) as functions of λ_x. The LHS is independent of λ_x and is shown by horizontal line $\delta f_e / f_x$. Fig. 1 illustrates the graph of $F(\lambda_x)$ which is downward sloping in the case of positive green elasticity. The intersection of the vertical line passing through $\bar{\lambda}$ and curve $F(\lambda_x)$ at point A determines $F(\bar{\lambda})$. In Fig.1, $\delta f_e / f_x$ is strictly lower than $F(\bar{\lambda})$. As a result, the intersection of $\delta f_e / f_x$ and curve $F(\lambda_x)$ determines the equilibrium export cutoff λ_x. It is obvious from Fig. 1 that there exists a sufficiently high level of f_x such that the export cutoff quality level λ_x exceeds the global environmental standard $\bar{\lambda}$.

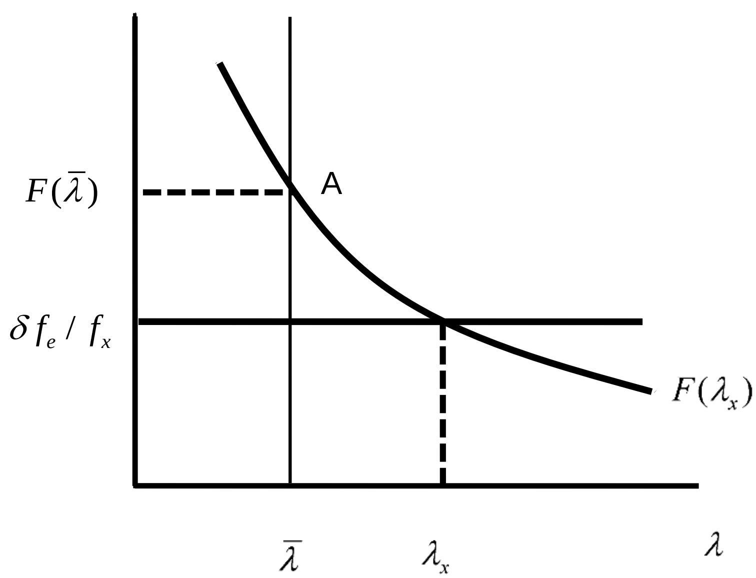

Figure 1. Determination of export cutoff λ_x when $\phi > 0$.

In the case of negative green elasticity ($\phi < 0$), the graph of $F(\lambda_x)$ (not shown in Fig.1) has positive slope and passes through point A. Thus for a sufficiently high level $\delta f_e / f_x$, such as $F(\bar{\lambda}) < \delta f_e / f_x$, the horizontal line is located above point A. In this case, the unique intersection between line $\delta f_e / f_x$ and upward-sloping curve $F(\lambda_x)$ determines the general-equilibrium value of export cutoff λ_x which is greater than the global environmental standard $\bar{\lambda}$. These considerations imply that Proposition 1 holds in general equilibrium.

Proposition 2: *There exists an export cutoff level which is unique and strictly greater than the global environmental standard ($\lambda_x > \bar{\lambda}$) satisfying equation* (31) *under the following parameter restrictions: if the green elasticity ϕ is positive (negative), then the ratio of expected entry costs to foreign-market entry costs $\delta f_e / f_x$ must be strictly lower (greater) than $F(\bar{\lambda})$. The intra-industry trade pattern described by Proposition 1 holds in general equilibrium.*

The equilibrium export cutoff environmental quality level λ_x and global environmental standard $\bar{\lambda}$ determine the average environmental quality levels of exports $\tilde{\lambda}_x$, domestically produced goods $\tilde{\lambda}_p$, and goods available for consumption $\tilde{\lambda}_c$. Equilibrium probabilities p_{in} and p_x are determined as well.[15]

Proposition 2 identifies the conditions providing separation between domestic firms and exporters. These conditions involve more parameters than those identified by the traditional theory of trade with heterogeneous firms. For instance, in Melitz (2003) the domestic cutoff quality level λ_d is given by setting the ex-post flow of domestic profits equal to the fixed costs of production $\pi_d(\lambda_d) = f$, where f denotes the fixed costs of entering the domestic market. Combining this equation with (11) and (18) yields the standard condition for the partitioning of firms by export status which occurs if and only if $\tau^{\sigma-1} f_x > f$. In contrast, in the present model the presence of a minimum (environmental) quality standard acts as the exogenous domestic cutoff quality level and implies that several additional parameters affect the partitioning of firms by export status. These additional parameters include δ, f_e, ϕ and parameters regulating the distribution of environmental quality.[16]

4. Effects of Environmental Standards and Trade Liberalization

In this section we analyze the effects of the global environmental standard $\bar{\lambda}$, and the impact of three types of trade liberalization: an increase in the number of trading partners n; a reduction in variable trade costs τ;

[15] The determination of the remaining endogenous variables such as the measure of varieties produced and consumed in each country, and aggregate profits is standard and omitted here based on space considerations.

[16] Proposition 2 applies to markets with binding product quality standards independently of pollution considerations. These quality standards include safety and health-hazard standards applied to pharmaceuticals, many agricultural products, and construction materials.

and a reduction in foreign-market entry costs f_x. We begin the analysis by establishing the impact of these parameters on the export cutoff level of environmental quality λ_x.

Lemma 3: *The equilibrium cutoff level of export environmental quality* λ_x*:*

(i) *declines (increases) with the global environmental standard* $\bar{\lambda}$ *if the green elasticity* ϕ *is positive (negative);*

(ii) *decreases (increases) with a reduction in per-unit trade costs* τ*, if the green elasticity* ϕ *is positive (negative);*

(iii) *decreases (increases) with a reduction in foreign-market entry costs* f_x*, if the green elasticity* ϕ *is positive (negative);*

(iv) *increases (decreases) with the number of trading partners* n*, if the green elasticity* ϕ *is positive (negative).*

Proof: Please see the Appendix.

The intuition behind Lemma 3 can be described with the help of zero-profit condition (31). A more stringent environmental standard $\bar{\lambda}$ leads to lower level of average profits $\bar{\pi}$ because it decreases the probability of successful entry. Similarly, trade liberalization in the form of lower per-unit trade costs τ or lower foreign-market access costs f_x reduces average profit by lowering the equilibrium domestic profit flow $\pi_d = \tau^{\sigma-1} f_x$. An initial reduction in average firm profit requires a compensating increase in the export cutoff quality λ_x to restore the zero-profit condition. Thus if the green elasticity is positive, then a reduction of λ_x raises average firm profit; whereas if the green elasticity is negative, then an increase in λ_x is required to increase average firm profit. In contrast, an increase in the number of trading partners n raises average profits by increasing the demand (as opposed the supply) for exports. The initial increase in average profits is reversed by raising (reducing) the export cutoff level λ_x if the green elasticity is positive (negative).

Armed with Lemma 3, we proceed to analyze the impact of global environmental standard and globalization on per-capita consumption Q, aggregate (and per-capita) pollution Z, and welfare $W = Q - Z$. Per capita consumption is given by the Dixit-Stiglitz (1977) sub-utility, as indicated by Eq. (2)

$$Q = \left[\int_{\omega\in\Omega} \left[\lambda(\omega)^{\alpha} \frac{q(\omega)}{L} \right]^{\rho} d\omega \right]^{1/\rho} = \left(\frac{L}{\sigma f_x} \right)^{1/(\sigma-1)} \frac{\lambda_x^{\phi}}{\tau}, \tag{33}$$

where the last expression is derived in the Appendix (please see Eq. (A15)). Per-capita (and aggregate) pollution Z can be written

$$Z = \frac{\varepsilon\rho L}{\tilde{\lambda}_c^{\psi}}\left[\frac{M_p}{M_c}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi-(\gamma+1)}\mu(\lambda)d\lambda + \frac{n}{\tau^{\sigma}}\frac{M_x}{M_c}\int_{\lambda_x}^{\infty}\lambda^{\psi-(\gamma+1)}\mu(\lambda)d\lambda\right]. \tag{34}$$

Eq. (34) was derived by aggregating Eq. (17) over all active firms and using Eq. (21) and Eq. (25). As a result, per-capita welfare can be expressed as

$$W = \left(\frac{L}{\sigma f_x}\right)^{1/(\sigma-1)}\frac{\rho\lambda_x^{\alpha-\gamma}}{\tau} - \frac{\varepsilon\rho L\left[\frac{M_p}{M_c}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi-(\gamma+1)}\mu(\lambda)d\lambda + \frac{n}{\tau^{\sigma}}\frac{M_x}{M_c}\int_{\lambda_x}^{\infty}\lambda^{\psi-(\gamma+1)}\mu(\lambda)d\lambda\right]}{\tilde{\lambda}_c^{\psi}}. \tag{35}$$

The following proposition states the effects of a higher environmental standard and trade liberalization

Proposition 3: *A more stringent environmental standard ($\bar{\lambda}\uparrow$), or trade liberalization in the form of a reduction in per-unit trade costs ($\tau\downarrow$), lower foreign-market access costs ($f_x\downarrow$), and greater number of trading partners ($n\uparrow$) has the following affects:*

(i) it increases per-capita consumption Q ;

(ii) and has ambiguous effects on aggregate pollution Z and thus welfare W .

Proof: Please see the Appendix.

We provide the following intuition behind Proposition 3. A higher environmental standard and any form of trade liberalization shifts resources from domestic R&D and domestic firms towards exporting firms. This resource shift reduces the measure of produced varieties and increases the measure of traded varieties. The latter effect dominates resulting in more varieties available for consumption, a lower green price index, a higher real wage and a higher level of per-capita consumption. In other words, in the absence of pollution ($\varepsilon = 0$), higher quality standards and trade liberalization increase welfare, as in Melitz (2003).

The presence of consumption-based pollution alters the standard beneficial welfare effects of trade highlighted by the theory of trade with heterogeneous firm. It is apparent from Eq. (35) that, depending on the parameter values such as a sufficiently large pollution intensity ε or number of consumers L , per-capita welfare W can be either positive or negative. In addition, a more stringent environmental standard or any facet of trade liberalization affects the level of pollution through several channels. Consider, for instance, the impact of a higher global environmental standard. According to Lemma 3 a higher $\bar{\lambda}$ decreases expected profits and the reward to environmental R&D. This leads to a lower measure of successful firms and produced varieties in each country. This leads to a shift of resources from firms serving the domestic market only to exporting firms and an increase in the measure of traded varieties resulting in more varieties available for consumption (and more pollution). The increase in varieties available for consumption intensifies competition and lowers the quantity consumed per variety. This channel reduces pollution since it depends on aggregate quantity consumed. Finally, an increase in $\bar{\lambda}$ has an ambiguous effect on average environmental quality which is inversely related to aggregate pollution. More formally, the dependence of aggregate pollution Z on the export cutoff λ_x is highly non-monotonic. As a result, the effect of a higher environmental standard on pollution and thus welfare is in general ambiguous. The appendix establishes formally that this ambiguity cannot be eliminated even in the special case where the global environmental standard is sufficiently high inducing all firms meeting the standard to become exporters ($\lambda_x = \bar{\lambda}$).

Trade liberalization affects pollution primarily through changes in the export cutoff quality level λ_x which has an ambiguous effect on pollution for reasons stated in the previous paragraph. Lower variable trade costs, lower fixed trade costs, or more trading partners increase profitability of exporting, raise the number of varieties consumed (increasing pollution), reduce the quantity consumed per variety (leading to lower pollution), and have an ambiguous impact on average quality of consumed varieties. The ambiguous effect of trade liberalization on aggregate pollution is translated into an ambiguous welfare effect.

5. Conclusions

This paper builds a simple monopolistic competition model of trade with heterogeneous polluters. Firms in this model charge constant markups over marginal costs and prices that are positively related to firm-specific environmental quality level. Consumption of varieties generates pollution. The model addresses the effects of environmental standards and trade liberalization on intra-industry trade patterns, global pollution and welfare. Trade liberalization takes the form of greater number of trade partners and lower fixed and variable trade costs.

The environmental content of intra-industry trade depends on model parameters captured by the green elasticity. When consumer preferences for environmental quality are strong relative to the costs of producing cleaner products, firm discovering cleaner products are more profitable and engage in exporting. In contrast, when consumers have weak preferences for environmental quality, firm discovering dirtier products are more profitable and become exporters. As a result, the model generates intra-industry “eco dumping” in the absence of comparative advantage, differences in environmental standards across countries, and international factor movements.

Stricter global environmental standards drive inefficient firms out of the market and induce entry into foreign markets. This leads to higher revenues and profits for all firms. The effects of higher environmental standards on aggregate pollution and welfare are ambiguous. Trade liberalization reduces profits and revenues of firms serving the domestic market; raises revenues and profits of exporting firms; and has an ambiguous effect on pollution and welfare.

The proposed analytical framework can be used to address a number of additional issues. For example, the ambiguous welfare effects of trade liberalization and environmental standards suggest the existence of optimum global standards and trade policies. Instead of consumption-based pollution one can introduced production based pollution. Finally, relaxing the assumption of symmetric countries would permit the analysis of country-specific environmental standards and trade policies. These issues are beyond the scope of the present paper and constitute fruitful avenues for future research.

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Appendix

A.1. Proof of Proposition 1

Lemma 1 implies that export revenue $r_x(\lambda)$ increases (decreases) in environmental quality λ if and only if $\phi > 0$ ($\phi < 0$). Substitute Eq. (11) into Eq. (18) to obtain $\pi_d(\lambda) = r_d(\lambda)/\sigma = f_x\tau^{\sigma-1}$. This equation reveals the following. If the level of trade barriers $f_x\tau^{\sigma-1}$ equals the minimum level of operating profit $\pi_d(\bar{\lambda}) = r_d(\bar{\lambda})/\sigma = f_x > 0$, then the global environmental standard $\bar{\lambda}$ solves Eq. (18) and thus the export cutoff coincides with the global environmental standard and all active firms export, i.e., $\lambda_x = \bar{\lambda}$. In the case of positive green elasticity ($\phi > 0$) operating profits increase with environmental quality. Therefore if the level of trade barriers $f_x\tau^{\sigma-1}$ is strictly greater than $\pi_d(\bar{\lambda})$, then the export cutoff environmental quality level is strictly greater than the environmental standard ($\bar{\lambda} < \lambda_x$). In this case, products with high environmental quality are exported, products with intermediate environmental quality are sold in the domestic market, and products with environmental quality below the global standard are not produced.

In the case of negative green elasticity ($\phi < 0$), where operating profits decrease with environmental quality, operating profit flow reaches its maximum when evaluated at the environmental standard, that is, $\pi_d(\bar{\lambda}) \geq \pi_d(\lambda)$ for $\bar{\lambda} < \lambda$. The aforementioned reasoning implies the following: if $\pi_d(\bar{\lambda}) = f_x\tau^{\sigma-1}$, then the export cutoff coincides with the environmental standard ($\lambda_x = \bar{\lambda}$), and all firms serve the domestic market only. Firms with environmental quality levels greater than the global standard earn negative profits from exporting. As a result, if the level of trade barriers $f_x\tau^{\sigma-1}$ is strictly less than $\pi_d(\bar{\lambda})$, the export cutoff quality level is strictly greater than the domestic cutoff quality level (global environmental standard), that is, $\bar{\lambda} < \lambda_x$. In this case, firms with low environmental quality products ($\bar{\lambda} < \lambda < \lambda_x$) engage in exporting, whereas firms with higher environmental quality products ($\lambda_x < \lambda$) serve the domestic market only.

A.2. Proof of Lemma 2

Let parameter $\psi = \phi(\sigma-1)$ denote the elasticity of firm revenue with respect to environmental quality λ. Because $\sigma > 1$ the sign of ψ is the same as the sign of green elasticity $\phi = \alpha - \gamma$. Every active firm must meet the environmental standard, that is, $1 < \bar{\lambda} < \lambda$. As a result, we have $\bar{\lambda}^{\psi} < \lambda^{\psi}$ if $\psi > 0$ and $\lambda^{\psi} < \bar{\lambda}^{\psi}$ if $\psi < 0$.

Consider first the case of a positive green elasticity ($\psi > 0$). Substituting $\lambda^{\psi} > \bar{\lambda}^{\psi}$ into the definition of $\tilde{\lambda}_p$, in Eq. (22), yields

$$\tilde{\lambda}_p^{\psi} = \frac{1}{1-G(\bar{\lambda})}\int_{\bar{\lambda}}^{\infty} \lambda^{\psi} g(\lambda) d\lambda > \frac{1}{1-G(\bar{\lambda})}\int_{\bar{\lambda}}^{\infty} \bar{\lambda}^{\psi} g(\lambda) d\lambda = \bar{\lambda}^{\psi} , \tag{A1}$$

which leads to $\tilde{\lambda}_p > \bar{\lambda}$. Let $H(\bar{\lambda}) = \frac{1}{1-G(\bar{\lambda})}\int_{\bar{\lambda}}^{\infty} \lambda^{\psi} g(\lambda) d\lambda$. Differentiating equation Eq. (22) yields

$$\frac{\partial \tilde{\lambda}_p}{\partial \bar{\lambda}} = \left(H(\bar{\lambda}) \right)^{(1-\psi)/\psi} \left[\frac{1}{\psi} \frac{\partial H}{\partial \bar{\lambda}} \right], \tag{A2}$$

where

$$\frac{1}{\psi}\frac{\partial H}{\partial \bar{\lambda}} = \frac{-\bar{\lambda}^{\psi} g(\bar{\lambda}) \left[1-G(\bar{\lambda}) \right] - \int_{\bar{\lambda}}^{\infty} \lambda^{\psi} g(\lambda) d\lambda \left[-g(\bar{\lambda}) \right]}{\psi \left[1-G(\bar{\lambda}) \right]^2} = \frac{g(\bar{\lambda}) \left[\tilde{\lambda}_p^{\psi} - \bar{\lambda}^{\psi} \right]}{\psi [1-G(\bar{\lambda})]} . \tag{A3}$$

Because $\psi > 0$ and $\tilde{\lambda}_p^{\psi} > \bar{\lambda}^{\psi}$, we have $(1/\psi)(\partial H / \partial \bar{\lambda}) > 0$. As a result, an increase in the global standard raises the average environmental quality of produced varieties ($\partial \tilde{\lambda}_p / \partial \bar{\lambda} > 0$). In the case of negative green elasticity ($\psi < 0$), inequality (A1) is reversed implying $\tilde{\lambda}_p^{\psi} < \bar{\lambda}^{\psi}$. Thus inequality $(1/\psi)(\partial H / \partial \bar{\lambda}) > 0$ holds, and therefore $\partial \tilde{\lambda}_p / \partial \bar{\lambda} > 0$. In sum, the average quality of domestically produced goods increases with the global environmental standard independently of the sign of the green elasticity.

The average export environmental quality $\tilde{\lambda}_x$ is defined in Eq. (23). In the case of positive green elasticity ($\phi > 0$), the export cutoff λ_x is the minimum of all export quality levels ($\lambda > \lambda_x$). As a result, inequality $\lambda^{\psi} > \lambda_x^{\psi}$ holds. Combining this inequality with Eq. (23) yields

$$\tilde{\lambda}_x^{\psi} = \frac{1}{1-G(\lambda_x)}\int_{\lambda_x}^{\infty} \lambda^{\psi} g(\lambda) d\lambda > \frac{1}{1-G(\lambda_x)}\int_{\lambda_x}^{\infty} \lambda_x^{\psi} g(\lambda) d\lambda = \lambda_x^{\psi} , \tag{A4}$$

leading to $\tilde{\lambda}_x > \lambda_x$.

Let $J(\lambda_x) = \frac{1}{1-G(\lambda_x)}\int_{\lambda_x}^{\infty} \lambda^{\psi} g(\lambda) d\lambda$. Differentiating Eq. (23) delivers

$$\frac{\partial \tilde{\lambda}_x}{\partial \lambda_x} = \left(J(\bar{\lambda}) \right)^{(1-\psi)/\psi} \left[\frac{1}{\psi} \frac{\partial J}{\partial \lambda_x} \right], \tag{A5}$$

where

$$\frac{1}{\psi}\frac{\partial J}{\partial \lambda_x} = \frac{-\lambda_x^{\psi} g(\lambda_x) \left[1-G(\lambda_x) \right] - \int_{\lambda_x}^{\infty} \lambda^{\psi} g(\lambda) d\lambda \left[-g(\lambda_x) \right]}{\psi \left[1-G(\lambda_x) \right]^2} = \frac{g(\lambda_x) \left[\tilde{\lambda}_x^{\psi} - \lambda_x^{\psi} \right]}{\psi [1-G(\lambda_x)]} . \tag{A6}$$

Since $\tilde{\lambda}_x^{\psi} > \lambda_x^{\psi}$ and $\psi > 0$ expression (A6) is positive. Thus if the green elasticity is positive ($\phi > 0$), then an increase in the export cutoff quality level raises the average quality of exports ($\partial\tilde{\lambda}_x / \partial\lambda_x > 0$).

Finally, consider the case of negative green elasticity ($\phi < 0$), where the export cutoff is the maximum of all export quality levels, i.e. $\lambda < \lambda_x$. In this case, where $\psi = \phi(\sigma - 1) < 0$, the following inequality holds: $\lambda^{\psi} > \lambda_x^{\psi}$. This implies that Eq. (A4) holds leading to inequality $\tilde{\lambda}_x^{\psi} > \lambda_x^{\psi}$. As a result, expression (A6) is negative and, therefore, $\partial\tilde{\lambda}_x / \partial\lambda_x < 0$. In words, if the green elasticity is negative ($\phi < 0$), then the average environmental quality of exports $\tilde{\lambda}_x$ declines with the export cutoff level λ_x.

A.3. Derivation of aggregate variables P, R and Q

Using Eq. (7), the green price index P (given by Eq. (6)) can be written as

$$
\begin{aligned}
P &= \left[\int_{\bar{\lambda}}^{\infty} \frac{\lambda^{\psi}}{\rho^{1-\sigma}} M_p \mu(\lambda) d\lambda + n \int_{\lambda_x}^{\infty} \frac{\tau^{1-\sigma}\lambda^{\psi}}{\rho^{1-\sigma}} M_x \mu(\lambda) d\lambda \right]^{1/(1-\sigma)} \\
&= \frac{M_c^{1/(1-\sigma)}}{\rho} \left[\frac{M_p}{M_c} \int_{\bar{\lambda}}^{\infty} \lambda^{\psi} \mu(\lambda) d\lambda + n \frac{M_x}{M_c} \int_{\lambda_x}^{\infty} \tau^{1-\sigma} \lambda^{\psi} \mu(\lambda) d\lambda \right]^{1/(1-\sigma)} \\
&= \frac{M_c^{1/(1-\sigma)}}{\rho} \left[\frac{M_p}{M_c} \tilde{\lambda}_p^{\psi} + n \frac{M_x}{M_c \tau^{\sigma-1}} \tilde{\lambda}_x^{\psi} \right]^{1/(1-\sigma)} \\
&= M_c^{1/(1-\sigma)} \tilde{\lambda}_c^{-\phi} / \rho.
\end{aligned}
\tag{A7}
$$

Under intra-industry trade, aggregate revenue $R = \int_0^{\infty} r(\lambda) M \mu(\lambda) d\lambda$ can be written as

$R = \int_{\bar{\lambda}}^{\infty} r_d(\lambda) M_p \mu(\lambda) d\lambda + n \int_{\lambda_x}^{\infty} r_x(\lambda) M_x \mu(\lambda) d\lambda$. Using Eq. (11) and Eq. (12) delivers

$$
\begin{aligned}
R &= \int_{\bar{\lambda}}^{\infty} r_d(\tilde{\lambda}_c) \frac{\lambda^{\psi}}{\tilde{\lambda}_c^{\psi}} M_p \mu(\lambda) d\lambda + \frac{n}{\tau^{\sigma-1}} \int_{\lambda_x}^{\infty} r_d(\tilde{\lambda}_c) \frac{\lambda^{\psi}}{\tilde{\lambda}_c^{\psi}} M_x \mu(\lambda) d\lambda \\
&= M_c \frac{r_d(\tilde{\lambda}_c)}{\tilde{\lambda}_c^{\psi}} \left[\frac{M_p}{M_c} \int_{\bar{\lambda}}^{\infty} \lambda^{\psi} \mu(\lambda) d\lambda + \frac{n}{\tau^{\sigma-1}} \frac{M_x}{M_c} \int_{\lambda_x}^{\infty} \lambda^{\psi} \mu(\lambda) d\lambda \right] \\
&= M_c r_d(\tilde{\lambda}_c).
\end{aligned}
\tag{A8}
$$

Aggregate quantity Q, which is defined by Eq. (2), can be written as

$$Q=\left[\int_{\bar{\lambda}}^{\infty}(P^{\sigma-1}\rho^{\sigma}\lambda^{\sigma(\alpha-\gamma)})^{\rho}M_{p}\mu(\lambda)d\lambda+n\int_{\lambda_x}^{\infty}(\tau^{-\sigma}P^{\sigma-1}\rho^{\sigma}\lambda^{\sigma(\alpha-\gamma)})^{\rho}M_{x}\mu(\lambda)d\lambda\right]^{1/\rho}$$

$$=\left[P^{(\sigma-1)\rho}\rho^{\sigma\rho}\left[\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}M_{p}\mu(\lambda)d\lambda+n\int_{\lambda_x}^{\infty}\frac{\lambda^{\psi}}{\tau^{\sigma-1}}M_{x}\mu(\lambda)d\lambda\right]\right]^{1/\rho}$$

$$=\left[M_{c}P^{(\sigma-1)\rho}\rho^{\sigma\rho}\tilde{\lambda}_{c}^{\psi}\right]^{1/\rho} \tag{A9}$$

$$=M_{c}^{\sigma/(\sigma-1)}\rho^{\sigma}P^{(\sigma-1)}\tilde{\lambda}_{c}^{\sigma(\alpha-\gamma)}$$

$$=\rho M_{c}^{1/(\sigma-1)}\tilde{\lambda}_{c}^{\phi}.$$

A.4. Proof of Lemma 3

Using Eq. (32), the zero-profit R&D condition (31) can be written as

$$\lambda_{x}^{\psi}\left[\delta\frac{f_e}{f_x}+\left[1-G(\lambda_x)\right]n\right]=\tau^{\sigma-1}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda+n\int_{\lambda_x}^{\infty}\lambda^{\psi}g(\lambda)d\lambda. \tag{A10}$$

Differentiating Eq. (A10) with respect to environmental standard $\bar{\lambda}$ yields

$$\frac{d\lambda_x}{d\bar{\lambda}}=-\frac{\tau^{\sigma-1}\bar{\lambda}^{\psi}g(\bar{\lambda})}{\psi\lambda_{x}^{\psi-1}\left[\delta\frac{f_e}{f_x}+\left[1-G(\lambda_x)\right]n\right]}. \tag{A11}$$

As a result $sign\left(d\lambda_x/d\bar{\lambda}\right)=-sign\left(\phi\right)$ because $\psi=\phi(\sigma-1)$. This proves part (i) of Lemma 3.

Differentiating Eq. (A10) with respect to per-unit trade costs τ, foreign-market entry costs f_x, and the number of trading partners n, respectively, delivers the following expressions:

$$\frac{d\lambda_x}{d\tau}=\frac{(\sigma-1)\tau^{\sigma-2}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda}{\psi\lambda_{x}^{\psi-1}\left[\delta\frac{f_e}{f_x}+\left[1-G(\lambda_x)\right]n\right]}; \tag{A12}$$

$$\frac{d\lambda_x}{df_x}=\frac{\delta f_e\lambda_x}{\psi\left[\delta f_e f_x+n\left[1-G(\lambda_x)\right]f_x^2\right]}; \tag{A13}$$

$$\frac{d\lambda_x}{dn}=\frac{\left[1-G(\lambda_x)\right]\left[\tilde{\lambda}_{x}^{\psi}-\lambda_{x}^{\psi}\right]}{\psi\lambda_{x}^{\psi-1}\left[\delta\frac{f_e}{f_x}+\left[1-G(\lambda_x)\right]n\right]}. \tag{A14}$$

Lemma 2 implies that $\tilde{\lambda}_x^{\psi} > \lambda_x^{\psi}$. As a result, the sign of Eq. (A12), Eq. (A13) and Eq. (A14) is the same as the sign of green elasticity ϕ : ($sign\left(d\lambda_x / d\tau\right) = sign\left(d\lambda_x / df_x\right) = sign(d\lambda_x / dn) = sign\left(\phi\right)$). This proves parts (ii), (iii) and (iv) of Lemma 3.

A.5. *Proof of Proposition 3*

Aggregate consumption, as indicated in Eq. (A9), is given by $Q = \rho M_c^{1/(\sigma-1)} \tilde{\lambda}_c^{\phi}$. Eq. (11) implies $\frac{r_d(\tilde{\lambda}_c)}{r_d(\lambda_x)} = \left(\frac{\tilde{\lambda}_c}{\lambda_x}\right)^{\psi} = \frac{L}{M_c \tau^{\sigma-1} \sigma f_x}$; where the last equality stems from national income identity $r_d(\tilde{\lambda}_c) M_c = L$ and use of Eq. (11) and Eq. (18) yielding $r_d(\lambda_x) = \tau^{\sigma-1} \sigma f_x$. As a result, $\tilde{\lambda}_c^{\psi} = \frac{L \lambda_x^{\psi}}{M_c \tau^{\sigma-1} \sigma f_x}$, which implies $\tilde{\lambda}_c^{\phi} = \left(\frac{L}{M_c \sigma f_x}\right)^{1/(\sigma-1)} \frac{\lambda_x^{\phi}}{\tau}$.

Per-capita consumption can then be written as

$$Q = \left(\frac{L}{\sigma f_x}\right)^{1/(\sigma-1)} \frac{\rho \lambda_x^{\phi}}{\tau} . \tag{A15}$$

Differentiating per-capital consumption (A15) with respect to $\bar{\lambda}$ yields

$$\frac{dQ}{d\bar{\lambda}} = \phi \frac{\rho}{\tau} \lambda_x^{\phi-1} \frac{d\lambda_x}{d\bar{\lambda}} \left(\frac{L}{\sigma f_x}\right)^{1/(\sigma-1)} . \tag{A16}$$

Substituting Eq. (A11) delivers

$$\frac{dQ}{d\bar{\lambda}} = \frac{\rho}{(\sigma-1)} \lambda_x^{\phi-\psi} \left(\frac{L}{\sigma f_x}\right)^{1/(\sigma-1)} \frac{\tau^{(\sigma-2)} \bar{\lambda}^{\psi} g(\bar{\lambda})}{\left[\delta \frac{f_e}{f_x} + [1-G(\lambda_x)] n\right]} > 0 . \tag{A17}$$

As a result, per-capita consumption increases with a stringent global environmental standard.

Differentiating aggregate consumption (A15) with respect to n yields

$$\frac{dQ}{dn} = \left(\frac{L}{\sigma f_x}\right)^{1/(\sigma-1)} \phi \frac{\rho}{\tau} \lambda_x^{\phi-1} \frac{d\lambda_x}{dn} , \tag{A18}$$

and substituting Eq. (A14) yields

$$\frac{dQ}{dn} = \left(\frac{L}{\sigma f_x}\right)^{1/(\sigma-1)} \frac{\rho}{(\sigma-1)\tau} \lambda_x^{\phi-\psi} \frac{[1-G(\lambda_x)][\tilde{\lambda}_x^{\psi} - \lambda_x^{\psi}]}{\left[\delta \frac{f_e}{f_x} + [1-G(\lambda_x)] n\right]} > 0 , \tag{A19}$$

which establishes that per-capita consumption increases with the number of trading countries.

Differentiating aggregate consumption (A15) with respect to τ yields

$$\frac{dQ}{d\tau} = \frac{\rho\lambda_x^{\phi}}{\tau^2}\left(\frac{L}{\sigma f_x}\right)^{1/(\sigma-1)}\left[\phi\frac{d\lambda_x}{d\tau}\frac{\tau}{\lambda_x} - 1\right], \tag{A20}$$

where $\phi\dfrac{d\lambda_x}{d\tau}\dfrac{\tau}{\lambda_x} = \dfrac{\tau^{\sigma-1}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda}{\left[\delta\dfrac{f_e}{f_x} + [1-G(\lambda_x)]n\right]\lambda_x^{\psi}}$.

Using R&D condition (31), this expression becomes

$$\phi\frac{d\lambda_x}{d\tau}\frac{\tau}{\lambda_x} = \frac{\tau^{\sigma-1}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda}{\tau^{\sigma-1}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda + n\int_{\lambda_x}^{\infty}\lambda^{\psi}g(\lambda)d\lambda} < 1. \tag{A21}$$

Therefore globalization causes by a decline in per-unit trade costs increases per-capita consumption ($dQ/d\tau < 0$).

Differentiating aggregate consumption (A15) with respect to f_x yields

$$\frac{dQ}{df_x} = \frac{1}{\tau(\sigma-1)}\left(\frac{L}{\sigma}\right)^{1/(\sigma-1)} f_x^{-1/(\sigma-1)-1}\lambda_x^{\alpha-\gamma}\left[\psi\frac{d\lambda_x}{df_x}\frac{f_x}{\lambda_x} - 1\right], \tag{A22}$$

where $\psi\dfrac{d\lambda_x}{df_x}\dfrac{f_x}{\lambda_x} = \dfrac{\delta f_e}{\delta f_e + n[1-G(\lambda_x)]f_x} < 1$. Therefore a reduction in fixed foreign market entry costs raises aggregate consumption ($dQ/df_x < 0$).

The effects of environmental quality standards and trade liberalization on pollution are ambiguous. As Eq. (34) indicates, this ambiguity stems from the highly non-monotonic relationship between pollution Z and the export cutoff quality λ_x. This relationship depends on the effect of the latter on average quality of varieties available for consumption, the share of traded varieties and properties of the conditional density function.

We illustrate formally this property in the (unrealistic) case where the environmental standard is sufficiently high so that all successful firms export ($\lambda_x = \bar{\lambda}$): the measure of exported varieties equals the measure of produced varieties ($M_x = M_p$); and Eqs. (22) and (24) imply $\tilde{\lambda}_c^{\psi} = \dfrac{M_p}{M_c}\dfrac{(1+n\tau^{1-\sigma})^{\sigma-1}}{[1-G(\bar{\lambda})]}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda$.

Substituting this expression and $\mu(\lambda) = g(\lambda)/[1-G(\bar{\lambda})]$ in Eq. (34) delivers

$$Z_{\lambda_x=\bar{\lambda}} = \frac{\varepsilon\rho L(1+n\tau^{-\sigma})\int_{\bar{\lambda}}^{\infty}\lambda^{\psi-(\gamma+1)}g(\lambda)d\lambda}{(1+n\tau^{1-\sigma})\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda} \tag{A23}$$

Differentiating (A23) with respect to $\bar{\lambda}$ yields

$$\frac{\partial Z_{\lambda_x=\bar{\lambda}}}{\partial\bar{\lambda}} = \frac{\varepsilon\rho L(1+n\tau^{-\sigma})\bar{\lambda}^{\psi}g(\bar{\lambda})\left[\int_{\bar{\lambda}}^{\infty}\lambda^{\psi-(\gamma+1)}g(\lambda)d\lambda - \bar{\lambda}^{-(\gamma+1)}\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda\right]}{(1+n\tau^{1-\sigma})\left[\int_{\bar{\lambda}}^{\infty}\lambda^{\psi}g(\lambda)d\lambda\right]^2} \tag{A24}$$

which is negative as $\bar{\lambda}\to 1$ and positive for sufficiently large values of $\bar{\lambda}$. In other words, even in the special case where all firms export, the effect of stringent environmental standards on pollution is ambiguous. This ambiguity carries over in the more general and realistic case where only a subset of firms export.