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Trade and the Environment: The Role of Firm Heterogeneity

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Abstract

In this paper, we derive a new effect of trade liberalization on the quality of the environment. We show that in the presence of heterogeneous firms, the aggregate volume of emissions is influenced by a reallocation effect resulting from an increase in the relative size of more productive firms. The relative importance of this reallocation effect and the scale effect well-known from the literature is affected by the emission intensity at the firm level. Domestic emissions decrease as a result of a unilateral tariff reduction if and only if firm-specific emission intensity decreases strongly with increasing firm productivity. As a result of the induced change in foreign emissions, domestic pollution can increase even if domestic emissions decrease.

1. Introduction

The recent economic literature has come up with a very useful way to systematically analyze the environmental effects of international trade. According to this now-standard classification, the overall effect of trade liberalization on aggregate emissions is decomposed into three partial effects: a *scale effect* resulting from the trade-induced augmentation of economic activity, a *technique effect* resulting from modified firm-level emission intensities, for example as a consequence of endogenous changes in environmental policies, and a *composition effect* resulting from a trade-induced change in the factor allocation across sectors.[1] In the theoretical framework predominantly used in this literature, trade is driven by international differences in relative factor endowments, but the trade pattern may be reversed by differences in country-specific environmental regulation (the pollution haven hypothesis).[2]

In this paper, we derive a new effect of trade liberalization on the environment that complements the three effects analyzed traditionally. For this purpose, we set up a one-sector model of an open economy with monopolistic competition.[3] Pollution is generated during the production process and exerts a direct negative effect on welfare. Firms differ in their productivity, as in Melitz (2003), and we assume that firm-level emission intensity is linked to firm-level productivity. While in our model firm-level emission intensity could increase or decrease with firm-level productivity, depending on parameter values, we focus—in line with empirical evidence (Forslid et al., 2011; Batrakova and Davies, 2012; Cui et al., 2012)—on the case that more productive firms are also environmentally more efficient. In this setup, unilateral trade liberalization affects average emission intensity in the economy via a previously

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unmodeled *reallocation effect*.[4] Although the traditional composition effect and the traditional technique effect are absent from our analysis, the reallocation effect exhibits characteristics of both these traditional effects and can be interpreted as an intra-sectoral version of the former and as an underlying determinant of the latter for the aggregate sector.

We show that the overall effect of a unilateral reduction of import tariffs on domestic emissions in our framework depends on the relative strength of the traditional scale effect, which leads to an increase in emissions, *ceteris paribus*, and the reallocation effect, which leads to a decrease in emissions, *ceteris paribus*. Overall, lowering import tariffs reduces domestic emissions if and only if firm-specific emission intensity decreases strongly with increasing firm productivity. Moreover, we analyze how domestic pollution, which depends on both domestic emissions and foreign emissions, is affected by a unilateral domestic tariff reduction. We show that as a result of induced factor reallocation in the non-reforming country, emissions leakage occurs (and therefore the effect on domestic pollution in the reforming country is less favorable than the effect on domestic emissions) unless firm-specific emission intensity in the non-reforming country does decrease strongly with increasing firm productivity.

Our paper is related to two recent theoretical contributions that model firm heterogeneity and emissions in an open economy context. Forslid et al. (2011) derive a positive relation between productivity and environmental efficiency at the firm level via endogenous emission abatement. Because of higher sales, more productive firms can afford to invest more in abatement. In Cui (2012), firms face the (binary) decision whether to switch to a less emission intensive production technology which reduces their marginal costs of production. Only the most productive firms can afford the additional fixed cost to upgrade and thereby become cleaner in the production process. In contrast to both papers, our focus is on the effect of trade liberalization on aggregate variables in the liberalizing country, in particular emissions and pollution, where we are able to derive closed-form solutions thanks to our parsimonious framework.

The remainder of the paper is organized as follows. Section 2 presents the basic model setup. Section 3 derives the open economy equilibrium. The effects of trade liberalization on aggregate variables, in particular on emissions and pollution, are analyzed in section 4. Section 5 concludes.

2. Model setup

Utility and Demand

We consider a world economy consisting of two countries, i and j, that are open to trade and produce varieties of a differentiated final good, q.[5] Each economy has a representative consumer using all his income for consumption of the differentiated good. Preferences of the representative consumer in country i are given by

$$W_i = U_i - \eta E_i, \tag{1}$$

where U_i denotes utility from the consumption of the differentiated good, whereas E_i is the level of pollution in country i. Parameter $\eta > 0$ reflects the preferences for environmental quality, where a higher value of η corresponds to a lower tolerance for pollution. Pollution in country i in turn is given by

$$E_i = E_i^d + \gamma E_j^d, \tag{2}$$

where E_i^d and E_j^d denote emissions originating from countries i and j, respectively. Parameter $\gamma \in [0, 1]$ is a measure for the degree of spillover of a particular pollutant across national borders, where $\gamma = 0$ denotes the case of a purely local pollutant, and $\gamma = 1$ the case of a global one.

Utility function U_i in country i is given by

$$U_i = \left[\int_{v \in V_i} q_i(v)^{\frac{\sigma-1}{\sigma}} dv \right]^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

where $q_i(v)$ denotes demand for variety v in country i, V_i is the set of varieties that are available for consumption in i, and $\sigma > 1$ is the elasticity of substitution between the different varieties of q in consumption. With R_i as the expenditure of the representative consumer, and $p_i(v)$ as the domestic price of variety v, utility maximization subject to the budget constraint $\int_{v \in V_i} p_i(v) q_i(v) dv = R_i$ leads to an iso-elastic demand function for each variety:

$$q_i(v) = R_i P_i^{\sigma-1} p_i(v)^{-\sigma}, \tag{4}$$

where P_i is the standard constant elasticity of substitution (CES) price index in country i.

Production

There is a continuum of firms, each producing one unique variety. Homogeneous labor is the only factor of production. The labor market is perfectly competitive, and the equilibrium wage rate in country i is denoted by w_i. The mass of domestic producers in country i is given by M_i^d, and together with exporters M_j^x from country j, these firms add up to the mass of producers that serve the domestic market: $M_i = M_i^d + M_j^x$. Firm entry into each market is described in section 3 below. The goods market in both countries is characterized by monopolistic competition, implying that firms take aggregate variables as given, while setting prices as a monopolist in the market for their own variety. In order to produce and distribute their output, firms have a (periodical) fixed labor input requirement f^l. The output of each firm is linear in variable labor input l_i^v and depends on the firm-specific productivity level φ: $q_i = \varphi l_i^v$. Denoting the marginal cost of selling variety v in market i by $c_i(v)$, the solution to a firm's price-setting problem is given by the constant markup rule:

$$p_i(v) = \frac{c_i(v)}{\rho}, \tag{5}$$

where $\rho \equiv (\sigma - 1)/\sigma$. Unit costs of selling in market i are equal to unit production costs $\tilde{c}_i(v) = w_i / \varphi(v)$ for domestic varieties. Imported varieties are subject to an *ad valorem* tariff of country i at rate τ_i, and we define $t_i \equiv 1 + \tau_i$ to simplify notation. The unit cost of imported varieties is then given by $c_i(v) = t_i \tilde{c}_j(v)$. From (4) and (5), domestic revenues and profits, respectively, of a country-i firm with productivity φ are given by

$$r_i^d(\varphi) = R_i P_i^{\sigma-1}\left(\frac{w_i}{\rho\varphi}\right)^{1-\sigma} \quad \text{and} \quad \pi_i^d(\varphi) = \frac{r_i^d(\varphi)}{\sigma} - w_i f^d. \tag{6}$$

Comparing two arbitrary firms 1 and 2 based in country *i*, and using the relationship between firm-level revenues, output and employment just derived, it follows directly that relative domestic outputs, revenues and variable employment levels of these firms are proportional to their relative productivities, a result well known from Melitz (2003):

$$\frac{q_i(\varphi_1)}{q_i(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma} \quad \frac{r_i^d(\varphi_1)}{r_i^d(\varphi_2)} = \frac{l_i^y(\varphi_1)}{l_i^y(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-1}. \tag{7}$$

Variable trade costs are zero, and therefore, in analogy to (4), demand from country *j* for country-*i* exports is given by

$$q_j(v) = R_j P_j^{\sigma-1} p_i(v)^{-\sigma}. \tag{8}$$

Export revenues and profits follow as

$$r_i^x = \frac{1}{t_j}\left[R_j P_j^{\sigma-1}\left(\frac{t_j w_i}{\rho\varphi}\right)^{1-\sigma}\right] \quad \text{and} \quad \pi_i^x = \frac{r_i^x}{\sigma} - w_i f^x, \tag{9}$$

respectively, where f^x is the fixed labor input requirement for exporting. Note that t_j enters the expression for export revenues of country-*i* firms twice: It appears in the term in square brackets since it affects the consumer price in country *j* and the implied quantity demanded. The term in square brackets then gives gross export revenues (including tariff payments), which have to be divided by t_j in order to give net export revenues.

Emissions-Generating Process

Emissions are generated by each firm as a joint output of production. An individual firm with productivity φ in country *i* generates emissions according to

$$e_i(\varphi) = \frac{1}{\varphi^{\alpha_i}} \times \begin{cases} q_i^d(\varphi) & \text{if firm does not export} \\ [q_i^d(\varphi) + q_i^x(\varphi)] & \text{if firm exports.} \end{cases} \tag{10}$$

The emission intensity $1/\varphi^{\alpha_i}$ is defined as the amount of pollution per unit of output, and as parametrized in (10) it changes monotonically with firm-specific productivity φ, where the extent to which this is the case depends on technology parameter α_i. For $\alpha_i < 0$, the emission intensity increases with firm productivity, whereas for $\alpha_i > 0$, emissions per output decrease in firm productivity. While our model is compatible with positive and negative values for α_i, we focus on the case of $\alpha_i > 0$, i.e. on the case of a negative correlation between productivity and emission intensity at the firm level.[6] In this case, the higher α_i, the stronger the decline in emission intensity with increasing firm productivity. Formally, it follows from (7) that for two firms of the same trade status relative emissions are given by

$$\frac{e_i(\varphi_1)}{e_i(\varphi_2)} = \left(\frac{\varphi_1}{\varphi_2}\right)^{\sigma-\alpha_i}. \tag{11}$$

There are three noteworthy special cases. In the borderline case of $\alpha_i = 0$, emission intensity is independent of firm productivity, and hence firm-specific emissions are directly proportional to output. With $\alpha_i = 1$, emissions are proportional to variable labor input. Since more productive firms employ more workers (given the status as exporter or non-exporter, respectively), high-productivity firms in this case still have higher total emissions than low-productivity firms. With $\alpha_i = \sigma$, the reduction in emission intensity in more productive firms is sufficiently strong to fully compensate the higher output, and the total emissions per firm, given its status as either exporter or non-exporter, are independent of firm productivity.

3. Open Economy Equilibrium

Firm entry into domestic production and into exporting is modeled as is standard in Melitz-type models: There is an unbounded pool of entrants deciding on paying a fixed market entry cost $w_i f^e$, which is immediately sunk, that allows them to draw labor productivity from the common cumulative distribution $G_i(\varphi)$. Knowing their productivity, they then decide whether to start producing, and which markets (only domestic, or domestic and foreign) to serve. We assume $f^x > f^d$, which ensures that only a subset of the domestic firms finds it profitable to export, independent of the value of τ_j. There is an infinite number of time periods, and every period an exogenous fraction δ of firms is hit by a negative shock and has to stop production. We focus on a steady-state equilibrium, in which the mass of firms is constant over time.

Firm productivities φ are Pareto distributed, with the lower bound normalized to one without loss of generality: $G_i(\varphi) = 1 - \varphi^{-k}$, with the corresponding density function $g_i(\varphi) = k\varphi^{-(k+1)}$, where we assume that $k > \sigma$ holds in order to ensure that average per-firm output is finite. With the *ex-ante* productivity distribution being Pareto, the *ex-post* productivity distributions of active firms, $\mu_i^d(\varphi)$ and of active exporting firms $\mu_i^x(\varphi)$ are also Pareto, with the respective lower bound being given by the productivity of the marginal domestic firm φ_i^d and the productivity of the marginal exporting firm φ_i^x:

$$\mu_i^d(\varphi) = \frac{k}{\varphi}\left(\frac{\varphi_i^d}{\varphi}\right)^k, \quad \mu_i^x(\varphi) = \frac{k}{\varphi}\left(\frac{\varphi_i^x}{\varphi}\right)^k. \tag{12}$$

Using the Pareto distribution, the free entry condition is given by

$$(\varphi_i^d)^{-k}\frac{\bar{\pi}_i}{\delta} = w_i f^e, \tag{13}$$

where $\bar{\pi}_i$ are the average profits of all active firms and $(\varphi_i^d)^{-k}$ is the *ex-ante* probability of a successful draw.

Zero Profit Conditions and Economy Averages

There are two zero profit conditions, each giving a general equilibrium relationship between the respective cutoff productivity (φ_i^d and φ_i^x), the fixed labor requirement of entering the respective market and endogenous economy-wide variables:

$$\frac{R_i P_i^{\sigma-1}}{\sigma}\left(\frac{w_i}{\rho\varphi_i^d}\right)^{1-\sigma} = w_i f^d, \tag{14}$$

$$\frac{R_j P_j^{\sigma-1}}{\sigma t_j}\left(\frac{t_j w_i}{\rho\varphi_i^x}\right)^{1-\sigma} = w_i f^x, \tag{15}$$

where we have used the definition of profits in equations (6) and (9). Hence, both zero profit conditions equalize the operating profits of the lowest-productivity firm serving the respective market to the fixed cost of serving this market.

The zero profit conditions can now be used to derive simple expressions for averages across firms for key economic variables. Average output of country i for the domestic market and the export market, respectively, are given by

$$\begin{aligned} \bar{q}_i^d &= \int_{\varphi_i^d}^{\infty} q_i^d(\varphi)\mu_i^d(\varphi)d\varphi = \left(\frac{k(\sigma-1)}{k-\sigma}\right) f^d \varphi_i^d, \\ \bar{q}_i^x &= \int_{\varphi_i^x}^{\infty} q_i^x(\varphi)\mu_i^x(\varphi)d\varphi = \left(\frac{k(\sigma-1)}{k-\sigma}\right) f^x \varphi_i^x, \end{aligned} \tag{16}$$

where we have substituted from equations (4), (8) and (12).[7] Using the link between firm-level output and firm-level emissions given by (10), average per-firm emissions owing to production for the domestic and export markets can be analogously derived as

$$\bar{e}_i^d = \left(\frac{k(\sigma-1)}{\alpha_i + k - \sigma}\right) f^d (\varphi_i^d)^{\alpha_i - 1} \quad \text{and} \quad \bar{e}_i^x = \left(\frac{k(\sigma-1)}{\alpha_i + k - \sigma}\right) f^x (\varphi_i^x)^{\alpha_i - 1}, \tag{17}$$

where we assume throughout that $\alpha_i > -(k - \sigma)$.[8] Using the same procedure as in the derivation of (16), average domestic revenues and export revenues, respectively, can be computed as

$$\bar{r}_i^d = \Theta\sigma w_i f^d \quad \text{and} \quad \bar{r}_i^x = \Theta\sigma w_i f^x, \tag{18}$$

where we have defined $\Theta \equiv k/[k - (\sigma - 1)] > 1$. Lastly, average profits for all firms in the economy can be written, following (18), as

$$\bar{\pi}_i = (\Theta - 1) w_i \left[f^d + \left(\frac{\varphi_i^d}{\varphi_i^x}\right)^k f^x \right], \tag{19}$$

where $(\varphi_i^d/\varphi_i^x)^k$ is the share of domestic firms that export.

Aggregate Variables

In general equilibrium, domestic labor needs to be fully employed. Taking into account labor's employment in market entry, as well as in production for the domestic market and for export, the full employment condition is written as

$$M_i^e f^e + M_i^d f^d + M_i^x f^x + M_i^d \int_{\varphi_i^d}^{\infty} \frac{q_i^d(\varphi)}{\varphi} \mu_i^d(\varphi) d\varphi + M_i^x \int_{\varphi_i^x}^{\infty} \frac{q_i^x(\varphi)}{\varphi} \mu_i^x(\varphi) d\varphi = L_i, \quad (20)$$

where M_i^e is the mass of firms entering the productivity draw and L_i is the exogenous labor supply of country i. As we show in the Appendix, it is straightforward to solve for the mass of domestic firms and domestic exporters, respectively, as

$$M_i^d = \Omega_i (\varphi_i^d)^{-k} \quad \text{and} \quad M_i^x = \Omega_i (\varphi_i^x)^{-k}, \quad (21)$$

where $\Omega_i \equiv \rho L_i/(k\delta f^e)$ is a measure of market size.

Aggregate output Q_i is given by $M_i^d \bar{q}_i^d + M_i^x \bar{q}_i^x$, and substituting from equations (16) and (21), we get:

$$Q_i = \Omega_i \left(\frac{k(\sigma - 1)}{k - \sigma} \right) \left(\frac{f^d}{(\varphi_i^d)^{k-1}} + \frac{f^x}{(\varphi_i^x)^{k-1}} \right), \quad (22)$$

and hence aggregate output is higher the lower the domestic cutoff productivity, and the lower the foreign cutoff productivity, ceteris paribus. Aggregate output Q_i as defined in (22) is not usually considered a variable of interest in Melitz-style trade models with heterogeneous firms, since welfare depends on the CES-aggregate of firm-specific outputs, rather than on their simple sum. Q_i is a relevant variable in the present context though, because in our framework a change in Q_i is the natural measure of the scale effect.

Aggregate domestic emissions can be derived in analogy to aggregate output as

$$E_i^d = \Omega_i \left(\frac{k(\sigma - 1)}{\alpha_i + k - \sigma} \right) \left(\frac{f^d}{(\varphi_i^d)^{\alpha_i + k - 1}} + \frac{f^x}{(\varphi_i^x)^{\alpha_i + k - 1}} \right). \quad (23)$$

Aggregate domestic emissions are hence determined by the technical parameter α_i, as well as by the equilibrium levels of the domestic entry and the export cutoff productivities φ_i^d and φ_i^x.

Cutoff Productivities

Having derived aggregate variables as a function of the various productivity cutoffs, we now turn to deriving links between those cutoffs. First, we use equation (19) to substitute for average profits in the free entry condition (13), which gives us a link between domestic and export cutoff productivities in country i:

$$\varphi_i^x = \left(\frac{f^x}{\delta f^e/(\Theta - 1) - f^d/(\varphi_i^d)^k} \right)^{\frac{1}{k}}. \quad (24)$$

Dividing the export cutoff productivity condition (15) for country j by the domestic cutoff productivity condition (14) for country i yields a link between φ_i^d and φ_j^x:

$$\varphi_i^d = \left[\left(\frac{w_i}{w_j t_i} \right)^{\sigma} \frac{f^d}{f^x} \right]^{\frac{1}{\sigma - 1}} \varphi_j^x. \quad (25)$$

Finally, a link between the export cutoff productivities of countries i and j can be derived from the trade balance condition

$$M_i^x \int_{\varphi_i^x}^{\infty} r_i^x(\varphi)\mu_i^x(\varphi)d\varphi = M_j^x \int_{\varphi_j^x}^{\infty} r_j^x(\varphi)\mu_j^x(\varphi)d\varphi,$$

which states that the value of exports at world market prices (identical to the export revenue of country-i firms) is equal to the value of imports at world market prices (identical to the export revenue of country-j firms). Substituting for average revenues from equation (18) and for the mass of firms from equation (21) leads to

$$\varphi_i^x = \left(\frac{L_i}{L_j}\frac{w_i}{w_j}\right)^{\frac{1}{k}} \varphi_j^x. \tag{26}$$

Together, equations (24) and (25), their respective analogues for market j, and (26) represent a system of five equations and, choosing labor in country j as the *numéraire*, we are left with the five endogenous variables φ_i^d, φ_i^x, φ_j^d, φ_j^x and w_i.

4. Trade Liberalization

We now turn to determining the effect of unilateral tariff changes by country i on three key variables of interest: aggregate output in country i, aggregate emissions of country i and pollution in country i, where the latter is jointly determined by emissions in countries i and j. The analysis proceeds in two steps: Following Felbermayr et al. (2013), we start by deriving the effect of a tariff change by country i on the relevant cutoff productivities in countries i and j. We then use these results to find the effect on our three key variables of interest.

Unilateral Tariff Reduction and Changes in Cutoff Productivities

The effect of a unilateral tariff reduction by country i on the four cutoff productivities follows from totally differentiating the system of equations derived at the end of section 3. As shown in the Appendix, differentiation of equations (24), (25) and (26) leads to

$$\hat{\varphi}_i^x = \mathcal{A}\hat{t}_i \tag{27}$$

$$\hat{\varphi}_i^d = \varepsilon_i^{dx}\mathcal{A}\hat{t}_i \tag{28}$$

$$\hat{\varphi}_j^x = \mathcal{A}\mathcal{B}\hat{t}_i \tag{29}$$

$$\hat{\varphi}_j^d = \varepsilon_j^{dx}\mathcal{A}\mathcal{B}\hat{t}_i \tag{30}$$

with

$$\mathcal{A} \equiv \frac{1}{\rho}\left[\frac{k-\rho\varepsilon_j^{dx}}{k(2-\varepsilon_i^{dx}-\varepsilon_j^{dx})-\rho(1-\varepsilon_i^{dx}\varepsilon_j^{dx})}\right] > 0, \quad \mathcal{B} \equiv \left(\frac{k-\rho}{k-\rho\varepsilon_j^{dx}}\right)$$

$$\varepsilon_i^{dx} \equiv \frac{\hat{\varphi}_i^d}{\hat{\varphi}_i^x}, \quad \varepsilon_j^{dx} \equiv \frac{\hat{\varphi}_j^d}{\hat{\varphi}_j^x},$$

where $\varepsilon_i^{dx}, \varepsilon_j^{dx} < 0,\ 0 < \mathcal{B} < 1$, and $\hat{x} \equiv dx/x$ denotes a percentage change in variable x.[9]

Hence, a higher degree of trade openness, modeled by a unilateral reduction in the import tariff in country i, reduces the productivity level of the marginal exporter in country i and increases the productivity of the marginal country-i producer. The intuition behind both effects is straightforward: Consumer expenditure shifts towards imported varieties, which leads to the exit of the least productive firms. The direct effect of this exit is to increase the domestic productivity cutoff. However, owing to the labor released by the exiting firms, the equilibrium wage w_i decreases, and the most productive non-exporting firms become competitive on the export market, implying a decrease in the export productivity cutoff. With $\mathcal{B}$ between 0 and 1, the effects on country-j cutoffs have the same sign as those on country-i cutoffs, but they are smaller in size.

Unilateral Tariff Reduction and Changes in Aggregate Variables

With trade liberalization having opposite effects on the two productivity cutoffs in country i, it follows from (22) that the overall effect on country-i output is the result of two partial effects going in opposite directions: Production for the domestic market declines, while export production increases. We show in the Appendix that total domestic output changes according to

$$\hat{Q}_i = -(k-1)\left[\frac{1-\varphi_i^d/\varphi_i^x}{1+f^d/f^x(\varphi_i^x/\varphi_i^d)^{k-1}}\right]\mathcal{A}\hat{t}_i. \tag{31}$$

Since both $(k - 1)$ and $\mathcal{A}$ are larger than zero, the sign of the term in square brackets ultimately determines the overall impact on aggregate production. Keeping in mind that $f^x > f^d$, and hence $\varphi_i^x > \varphi_i^d$, it follows immediately that the term in square brackets is $\in (0, 1)$. This in turn implies that trade liberalization, i.e., $\hat{t}_i < 0$, increases aggregate domestic output.

Domestic emissions, in turn, change in response to the liberalization of trade according to

$$\hat{E}_i^d = -(\alpha_i + k - 1)\left[\frac{1-(\varphi_i^x/\varphi_i^d)^{\alpha_i-1}}{1+f^d/f^x(\varphi_i^x/\varphi_i^d)^{k-1+\alpha_i}}\right]\mathcal{A}\hat{t}_i. \tag{32}$$

Given our earlier assumptions, the first term is always negative, while $\mathcal{A}$ is positive, as shown above. Hence, the sign of the term in square brackets determines the overall effect on domestic emissions, which decrease in case of a negative sign. The denominator is always positive and larger than 1 independent of α_i, while the numerator is a decreasing function in α_i, starting with positive values for small α_i and turning negative for $\alpha_i > 1$. Hence, trade liberalization increases domestic emissions if and only if the technology parameter α_i is smaller than 1. We summarize our key result as follows:

Proposition 1. *The unilateral reduction of import tariffs by country i reduces aggregate country-i emissions via a reallocation of resources to more productive firms if and only if $\alpha_i > 1$, and therefore emission intensities decrease strongly with firm productivity.*

The economic intuition for the effect of trade liberalization on country-i emissions is as follows. E_i^d is affected via two channels: First, a scale effect familiar from Grossman and Krueger (1993) increases domestic emissions in accordance with increased aggregate output. Second, trade liberalization leads to a reallocation of production towards more productive firms, which produce with a lower firm-specific emission intensity. This reallocation effect reduces domestic emissions, *ceteris paribus*. For $\alpha_i = 1$, these two opposing effects exactly offset each other, whereas for any value of α_i larger than 1, the reallocation effect dominates the scale effect, and domestic emissions are smaller in a more open economy.

An interesting case arises for the range of α_i between 1 and σ. On the one hand, the reallocation effect dominates the scale effect, and aggregate domestic emissions unambiguously decrease. On the other hand, however, more productive firms generate more emissions, *ceteris paribus*, as can be deduced from (11). This shows that more open trade can reduce aggregate emissions by the liberalizing country even if it leads to a reallocation of resources to those firms that—owing to their larger scale—generate more emissions. The scenario of $1 < \alpha_i < \sigma$ matches well recent empirical findings. It features an overall reduction of domestic emissions (see, for example, Antweiler et al. (2001) and the literature surveyed by McAusland (2010)), lower emissions intensities of larger firms (Cole et al., 2013), and fewer emissions of exporters relative to non-exporters when controlling for output (Holladay, 2010; Forslid et al., 2011; Cui et al., 2012).

It is instructive to relate the effect of trade liberalization on emissions in the heterogeneous firms' framework to the effects derived in the literature. Both the traditional technique effect and the traditional composition effect are absent from our analysis. However, our newly identified reallocation effect can be alternatively interpreted as either one of these effects. Although the emission intensity of an individual firm remains unchanged when trade is liberalized, the average emission intensity of the industry is reduced in accordance with an increase in the average productivity. Or, put differently, the technique effect can be identified for the aggregate sector.[10] Alternatively, the reallocation effect can be interpreted as an intra-sectoral composition effect. Trade leads to a change in the market structure within the analyzed sector. Labor is reallocated to the most productive firms, which are, under the assumption of a positive relation between labor productivity and environmental efficiency, the firms with the lowest emission intensities.[11]

In order to fully assess the effect of trade liberalization by country i on the level of pollution in country i, we need to take into account the effect on country-j emissions. This is because according to equation (2) domestic pollution is generally not determined by domestic emissions alone. In the case of a non-local pollutant, i.e. $\gamma \neq 0$, foreign emissions play a crucial role in determining the overall effect of a unilateral trade liberalization on consumers in the tariff reducing country i. Total pollution in country i changes according to

$$\hat{E}_i = \beta_i \hat{E}_i^d + (1-\beta_i)\gamma \hat{E}_j^d, \tag{33}$$

with $\beta_i \equiv E_i^d / E_i$ being the share of domestic emissions in total pollution in country i.

Similar to equation (32), the percentage change in foreign emissions in response to the tariff reduction of country i is determined by

$$\hat{E}_j^d = -(\alpha_j + k - 1)\left[\frac{1-(\varphi_j^x/\varphi_j^d)^{\alpha_j - 1}}{1 + f^d/f^x\,(\varphi_j^x/\varphi_j^d)^{k-1+\alpha_j}}\right]\mathcal{A}\mathcal{B}\hat{t}_i. \tag{34}$$

Again the technology parameter (α_j here) determines the relative strength of the partial scale and reallocation effect and thus the overall impact on country-j emissions. Given an initial symmetry between both countries, the effect is larger in the reforming country i since $\mathcal{B} < 1$. In general, for $\alpha_i, \alpha_j \geq 1$ or $\alpha_i, \alpha_j \leq 1$, the effect of trade liberalization on emissions is of the same sign in both countries. Hence, the effect on country-i emissions, whatever its sign, is magnified for country-i pollution.

In the case of either $\alpha_i > 1 > \alpha_j$ or $\alpha_j > 1 > \alpha_i$, this magnification result no longer holds. For instance, a unilateral trade liberalization that decreases emissions in country i (owing to $\alpha_i > 1$) increases country-j emissions if $\alpha_j < 1$, and therefore trade liberalization does not lower domestic pollution by as much as it lowers domestic emissions. For a sufficiently high share $1 - \beta_i$ of foreign emissions in country-i pollution, the increased emissions in j can even more than offset the emissions reduction in country i, thereby leading to an overall increase in country-i pollution. The scenario just described has obvious similarities to the carbon leakage phenomenon, although in our case the unfavorable effect on foreign emissions results from a change in trade policy, rather than from a change in environmental regulation. The results of this section are summarized as follows:

Proposition 2. *In the case of non-local pollutants, a unilateral reduction of import tariffs by country i that reduces country-i emissions also reduces country-i pollution if either $\alpha_j > 1$, i.e. emission intensity is strongly decreasing with firm productivity in country j, or the share of country j in country-i pollution is sufficiently small.*

We finally turn briefly to a discussion of the effect that trade liberalization has on welfare, i.e. the utility of the representative consumer given by equation (1). Felbermayr et al. (2013) have shown that the optimal tariff for the present general setting, but without emissions, is equal to $t_i^o = (k - \rho\varepsilon_j^{dx})/(k - \rho) > 1$, and in fact that this tariff leads to a first best equilibrium. On the one hand the optimal tariff in this case corrects two distortions present in the model, namely the mark-up distortion (consumer prices reflect the opportunity cost of imported products in free trade, but they exceed the resource cost of domestic products by the monopolistic markup) and the consumer surplus externality (higher import spending increases the mass of available imported varieties, an effect ignored by the individual allocating his expenditure) as discussed in Demidova and Rodríguez-Clare (2009). On the other hand terms-of-trade considerations are additionally taken into account in the large economy case.

Equations (1) and (2) show that this result is modified in a straightforward way in the present context, in which production causes emissions. Whenever the degree of trade openness has an effect on pollution in country i, the value for the optimal tariff deviates from $t_i^o = (k - \rho\varepsilon_j^{dx})/(k - \rho)$ in a well-defined way. Starting from t_i^o, small deviations have only a second-order effect on the three non-environmental distortions (this is what makes the tariff optimal in the setting of Felbermayr et al. (2013) to begin with), and hence the optimal direction to deviate is the one that leads to lower pollution in country i. This in turn depends on the technology parameters α_i and α_j as well as on γ and β_i: A tariff reduction diminishes country-i pollution whenever Proposition 2 holds. Hence, the optimal tariff particularly is smaller than t_i^o for the empirically plausible case α_i, $\alpha_j > 1$, and larger than t_i^o in the case of a parameter constellation leading to an increase in country-i pollution.

5. Conclusions

The traditional literature derives three principal channels through which trade liberalization affects the environment: an emission increasing scale effect caused by an augmentation of economic activity, an emission reducing technique effect arising from changes in emission intensities, following stricter environmental policies and a composition effect, whose sign and strength depends on comparative advantages of the considered country. The latter effect is the consequence of a change in a country's industrial structure owing to specialization.

In this paper we have shown that, by means of a trade model with monopolistic competition and heterogeneous firms, a fourth principal channel can be derived. By positively linking a firm's productivity to its environmental efficiency, the trade-induced increase in aggregate productivity translates into a reduction of aggregate emission intensity. The least productive firms exit the market; resources are reallocated towards the most productive and least emission intensive firms. This reallocation effect reduces aggregate domestic emissions, ceteris paribus, but owing to the presence of the scale effect, the overall impact of more open trade on domestic emissions is negative if and only if firm-specific emission intensity decreases strongly with increasing firm productivity. While in our model, both the traditional composition effect, and the traditional technique effect are absent, the reallocation effect can be interpreted as an intra-sectoral composition effect and as a technique effect for the aggregate sector.

In the case of a non-local pollutant, emissions generated in the rest of the world also contribute to total pollution in the country under consideration. Given an initial symmetry between the two countries, foreign emissions are affected by the unilateral tariff reform in the same direction but to a lesser extent than those in the reforming country. Hence, with symmetric countries the effect on emissions in the liberalizing country, whatever its sign, is magnified for pollution in this country. We also explore country asymmetries and derive conditions under which trade liberalization can lead to higher pollution in the reforming country even if local emissions fall.

Since the model has only one sector and one factor of production, determinants of comparative advantage and the resulting consequences on environmental quality cannot be addressed. Hence, a potentially worthwhile extension would be to embed the present framework of a monopolistically competitive sector with heterogeneous firms into a model of the Heckscher-Ohlin type à la Bernard et al. (2007).

Appendix

Average Output and Exports

Average output of firms in country i for the domestic market can be calculated by means of the ex post productivity distribution of active firms, given in equation (12), as follows:

$$\begin{aligned}\bar{q}_i^d &= \int_{\varphi_i^d}^{\infty} q_i^d(\varphi)\mu_i^d(\varphi)d\varphi = \int_{\varphi_i^d}^{\infty} R_i P_i^{\sigma-1}\left(\frac{w_i}{\rho\varphi}\right)^{-\sigma}\mu_i^d(\varphi)d\varphi \\ &= R_i P_i^{\sigma-1}\left(\frac{w_i}{\rho}\right)^{-\sigma} k(\varphi_i^d)^k \int_{\varphi_i^d}^{\infty}\varphi^{\sigma-k-1}d\varphi \\ &= \left(\frac{k}{k-\sigma}\right) R_i P_i^{\sigma-1}\left(\frac{w_i}{\rho\varphi_i^d}\right)^{-\sigma} \\ &= \left(\frac{k}{k-\sigma}\right)(\sigma-1) f^d \varphi_i^d,\end{aligned} \tag{A1}$$

where the last equation follows from zero cutoff profit condition (14). Output produced for the export market averaged over all exporting firms can be analogously calculated, using the zero export cutoff profit condition (15) in the last line:

$$\bar{q}_i^x = \int_{\varphi_i^x}^{\infty} q_i^x(\varphi)\mu_i^x(\varphi)d\varphi = \int_{\varphi_i^x}^{\infty} R_j P_j^{\sigma-1}\left(\frac{t_j w_i}{\rho\varphi}\right)^{-\sigma}\mu_i^x(\varphi)d\varphi$$
$$= \left(\frac{k}{k-\sigma}\right)(\sigma-1)f^x\varphi_i^x. \tag{A2}$$

Mass of Incumbent Firms

The full employment condition given in equation (20) can be simplified by using the equilibrium stability condition $M_i^e = \delta(\varphi_i^d)^k M_i^d$ and $M_i^x = (\varphi_i^d/\varphi_i^x)^k M_i^d$ as well as equations (14) and (15) to solve the integrals. Hence,

$$M_i^d\left[\delta f^e(\varphi_i^d)^k + f^d + \left(\frac{\varphi_i^d}{\varphi_i^x}\right)^k f^x + \Theta(\sigma-1)f^d + \left(\frac{\varphi_i^d}{\varphi_i^x}\right)^k \Theta(\sigma-1)f^x\right] = L_i. \tag{A3}$$

Rearranging terms and using average profits equation (19) yields

$$M_i^d\left[\delta f^e(\varphi_i^d)^k + (1+\Theta(\sigma-1))\left(\frac{\bar{\pi}_i}{w_i(\Theta-1)}\right)\right] = L_i. \tag{A4}$$

By means of the free entry condition (13) this can be rewritten as

$$M_i^d\left[\delta f^e(\varphi_i^d)^k\left(1+\frac{1+\Theta(\sigma-1)}{\Theta-1}\right)\right] = L_i. \tag{A5}$$

Noting that $\Theta\sigma/(\Theta-1) = k/\rho$, the mass of incumbent firms M_i^d is given by

$$M_i^d = L_i\left(\frac{k\delta f^e}{\rho}(\varphi_i^d)^k\right)^{-1}. \tag{A6}$$

Applying the share of exporters $(\varphi_i^d/\varphi_i^x)^k$, then gives the mass of exporting firms M_i^x.

Derivation of Equations (27)–(30)

Totally differentiating (24)–(26), gives the system of equations:

$$\hat{\varphi}_i^d = \varepsilon_i^{dx}\hat{\varphi}_i^x \tag{A7}$$

$$\hat{\varphi}_j^d = \varepsilon_j^{dx}\hat{\varphi}_j^x \tag{A7′}$$

$$\hat{\varphi}_j^x = \hat{\varphi}_i^d - \frac{1}{\rho}\hat{w}_i + \frac{1}{\rho}\hat{t}_i \tag{A8}$$

$$\hat{\varphi}_i^x = \hat{\varphi}_j^d + \frac{1}{\rho}\hat{w}_i \tag{A8′}$$

$$\hat{\varphi}_i^x = \hat{\varphi}_j^x + \frac{1}{k}\hat{w}_i \tag{A9}$$

where

$$\varepsilon_i^{dx} \equiv \frac{\hat{\varphi}_i^d}{\hat{\varphi}_i^x} = -\frac{f^x}{f^d}\left(\frac{\varphi_i^d}{\varphi_i^x}\right)^k < 0 \quad \text{and} \quad \varepsilon_j^{dx} \equiv \frac{\hat{\varphi}_j^d}{\hat{\varphi}_j^x} = -\frac{f^x}{f^d}\left(\frac{\varphi_j^d}{\varphi_j^x}\right)^k < 0,$$

and recalling that $\hat{w}_j = 0$ by choice of the numéraire, and that $\hat{t}_j = 0$ by choice of our comparative static exercise.

Combining (A7) and (A8) as well as Eqs. (A7′) and (A8′), respectively, gives

$$\hat{\varphi}_j^x = \varepsilon_i^{dx}\hat{\varphi}_i^x - \frac{1}{\rho}\hat{w}_i + \frac{1}{\rho}\hat{t}_i \tag{A10}$$

$$\hat{\varphi}_i^x = \varepsilon_j^{dx}\hat{\varphi}_j^x + \frac{1}{\rho}\hat{w}_i \tag{A10′}$$

and together with equation (A9) this gives us a system of three equations in three endogenous variables. Using (A9) and (A10) as well as (A10) and (A10′) to eliminate $\hat{\varphi}_j^x$, we get two equations linking the endogenous variables $\hat{w}_i$ and $\hat{\varphi}_i^x$:

$$\hat{w}_i = \frac{k\rho}{k-\rho}\left[\frac{1}{\rho}\hat{t}_i - (1-\varepsilon_i^{dx})\hat{\varphi}_i^x\right]$$

$$\hat{w}_i = \frac{\rho}{1-\varepsilon_j^{dx}}\left[(1-\varepsilon_i^{dx}\varepsilon_j^{dx})\hat{\varphi}_i^x - \frac{\varepsilon_j^{dx}}{\rho}\hat{t}_i\right].$$

Solving this set of equations for $\hat{\varphi}_i^x$ gives

$$\hat{\varphi}_i^x = \frac{1}{\rho}\left[\frac{k-\rho\varepsilon_j^{dx}}{k(2-\varepsilon_i^{dx}-\varepsilon_j^{dx})-\rho(1-\varepsilon_i^{dx}\varepsilon_j^{dx})}\right]\hat{t}_i. \tag{A11}$$

Note that both the nominator and denominator of the term in square brackets are always positive. Since ε_i^{dx} and ε_j^{dx} are both smaller than zero, the lower bound of the denominator is $2k - \rho$ which is always positive by assumption of the parameter values.

To find the effect of $\hat{t}_i$ on the export productivity cutoff in the non-reforming country *j*, we now use equations (A9) and (A10′) as well as (A10) and (A10′) to eliminate $\hat{\varphi}_i^x$. Solving the resulting set of equations for $\hat{\varphi}_j^x$ gives

$$\hat{\varphi}_j^x = \frac{1}{\rho}\left[\frac{k-\rho}{k(2-\varepsilon_i^{dx}-\varepsilon_j^{dx})-\rho(1-\varepsilon_i^{dx}\varepsilon_j^{dx})}\right]\hat{t}_i, \tag{A12}$$

and hence

$$\frac{\hat{\varphi}_j^x}{\hat{t}_i} = \left(\frac{k-\rho}{k-\rho\varepsilon_j^{dx}}\right)\frac{\hat{\varphi}_i^x}{\hat{t}_i}.$$

Derivation of Equations (31) and (32)

It is convenient to first solve the more general case of a change in domestic emissions $\hat{E}_i^d$. Totally differentiating equation (23) and expressing it in terms of the rate of change yields

$$\hat{E}_i^d = -(\alpha_i + k - 1) \times \left[\frac{f^d / (\varphi_i^d)^{\alpha_i+k-1}}{f^d / (\varphi_i^d)^{\alpha_i+k-1} + f^x / (\varphi_i^x)^{\alpha_i+k-1}} \hat{\varphi}_i^d + \frac{f^x / (\varphi_i^x)^{\alpha_i+k-1}}{f^d / (\varphi_i^d)^{\alpha_i+k-1} + f^x / (\varphi_i^x)^{\alpha_i+k-1}} \hat{\varphi}_i^x \right]. \tag{A13}$$

Using (A7) one can then substitute for $\hat{\varphi}_i^d$, which gives

$$\hat{E}_i^d = -(\alpha_i + k - 1) \left[\frac{-f^x (\varphi_i^d)^{1-\alpha} / (\varphi_i^x)^k + f^x / (\varphi_i^x)^{\alpha_i+k-1}}{f^d / (\varphi_i^d)^{\alpha_i+k-1} + f^x / (\varphi_i^x)^{\alpha_i+k-1}} \right] \hat{\varphi}_i^x. \tag{A14}$$

Finally, rearranging terms results in equation (32) given in the text. Setting $\alpha_i = 0$, the change of aggregate domestic output is determined as in equation (31).

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Notes

1. This classification has been introduced by Grossman and Krueger (1993) in an empirical paper, while a model-based definition has been provided by Copeland and Taylor (1994). The classification exclusively focuses on the indirect effects of trade on the environment, abstracting from environmental effects of international transport. See McAusland (2010) and Cristea et al. (2013) for empirical evidence of direct environmental effects of trade.
2. These mechanisms have been well studied empirically. Antweiler et al. (2001) simultaneously estimate the scale, technique and composition effects of trade on the concentration of SO_2. Their findings suggest a comparably small composition effect and the dominance of a positive impact of trade liberalization on environmental quality, notably driven by the technique effect. Cole and Elliott (2003) derive similar results regarding the reduction of SO_2 emissions, but show that the effect may be less beneficial for other pollutants. Frankel and Rose (2005), and Managi et al. (2009) account for the potential endogeneity of income and trade openness. McAusland (2010) points out that trade liberalization tends to be environmentally beneficial primarily for local pollutants. Managi et al. (2009) furthermore highlight the difference between Organisation for Economic Cooperation and Developmen (OECD) and non-OECD countries, while McAusland and Millimet (2013) focus on the difference between inter- and intranational trade.

3. Monopolistic competition models have been somewhat neglected in the trade and environment literature. Exceptions include Rauscher (1997), Gürtzgen and Rauscher (2000), Haupt (2000, 2006), Pflüger (2001), and Benarroch and Weder (2006). See also Copeland and Taylor (2003), and the surveys by Sturm (2003), and more recently Copeland (2011), who all include brief sections discussing models with monopolistic competition.
4. Melitz and Trefler (2012) use this term to describe the increase in allocative intra-industry efficiency owing to trade. They do not refer to the impact of trade on the environment, though.
5. The analysis below will focus on country i, with the understanding that analogous equations hold for the other country.
6. Hereby we follow the recent empirical literature which tends to find to a negative relation (cf. Forslid et al., 2011; Batrakova and Davies, 2012; Cui et al., 2012).
7. The details of the derivation are deferred to the Appendix.
8. This inequality holds automatically if $\alpha_i > 0$, which is the case we focus on here.
9. The results in equations (27)–(30) replicate the results of Lemma 1b) in Felbermayr et al. (2013).
10. A not-controlled-for reallocation effect may also explain why "[the] technique effect seems surprisingly strong" in the sector-level estimation of Antweiler et al. (2001, p. 894) driving the positive impact of trade on environmental quality.
11. Copeland (2010, p. 209) verbally describes an intra-sectoral version of the composition effect as follows: "There are also firm-level effects: the recent international trade literature has emphasised that only the most productive firms tend to export and so trade tends to cause some firms to expand and others to contract or exit. . . . If emission intensities vary across industries [and] firms . . . then these composition effects will have a direct influence on environmental outcomes."