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TRADE, TRANSBOUNDARY POLLUTION AND MARKET SIZE

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ABSTRACT

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This paper uses a monopolistic competitive framework with many sectors to study the impact of trade liberalization on local and global emissions. We focus on the interplay of the pollution haven effect and the home market effect and show how a large-market advantage can counterbalance a high emission tax, implying that trade liberalization leads to lower global emissions. Generally, our results suggest that relative market size, the level of trade costs, the ease of abatement, and the degree of product differentiation at the sector level are relevant variables for empirical studies on trade and pollution.

JEL Classification: F12 and F15
Keywords: market size, trade liberalization and transboundary pollution

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Trade, Transboundary Pollution and Market Size *

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March 2013

Abstract

This paper uses a monopolistic competitive framework with many sectors to study the impact of trade liberalization on local and global emissions. We focus on the interplay of the pollution haven effect and the home market effect and show how a large-market advantage can counterbalance a high emission tax, implying that trade liberalization leads to lower global emissions. Generally, our results suggest that relative market size, the level of trade costs, the ease of abatement, and the degree of product differentiation at the sector level are relevant variables for empirical studies on trade and pollution.

JEL Classification: D21, F12, F15

Keywords: market size, emission tax, trade liberalization

1 Introduction

An extensive literature explores the mechanisms through which trade can affect the environment. A topical concern is that trade liberalization allows firms to locate production in countries with lower emission standards: the 'pollution haven hypothesis' (PHH).[1] While there is considerable theoretical support and an intuitive appeal for the PHH, it has been hard to identify empirically, and the surveys by Copeland and Taylor (2004) and Brunnermeier and Levinson (2004) find conflicting results across the literature. Recent studies provide further conflicting evidence.[2]

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[1]We will follow Copeland and Taylor (2004) and distinguish between the pollution haven effect (PHE), meaning that firms adjust their operation or location in response to differences in environmental taxes, and the pollution haven hypothesis (PHH) where trade liberalisation induces firms to relocate to the low tax country.

[2]Sector level data for pollution intensive industries in the U.S. has not been disproportionately affected by tariff changes Ederington, Levinson, and Minier (2005). However, sector level data for the U.S. also shows that higher

The present paper suggests a new set of theoretical reasons that may help reconcile the contradictory empirical results reported in the PHH literature. The analysis juxtaposes relative market size and asymmetric emission tax levels in determining the patterns of production and pollution. Our theoretical findings suggest that relative market size, ease of abatement and product differentiation could be important variables in empirical studies examining trade liberalization and transboundary pollution.

We use a monopolistic competition trade model with several manufacturing sectors and transboundary emissions generated from the production of the manufactured goods with pollution abatement by the firm à la Copeland and Taylor (1994). The model is specified in terms of a transboundary pollutant, and indeed we have greenhouse gas emissions in mind; however, absent welfare considerations, the analysis applies equally to local pollutants. To focus on effects related to the monopolistically competitive framework, we assume that countries are identical except for their size. Thus, there is intra-industry trade (within industry trade) with differentiated products, but no role for comparative advantage. In this type of framework, the number of firms increases more rapidly than output as a country becomes larger. The reason for this is that firms concentrate in the larger market to save on transportation costs. This effect has been dubbed the 'home market effect' (HME) by Helpman and Krugman (1985). At the same time, trade liberalization does not only affect the HME but also the PHH and the outcome of trade liberalization on global emissions will therefore depend on the interplay of the HME and the PHH.

We show how the HME dominates firm location when the size difference between markets is large, in sectors where abatement is easy, and when the degree of differentiation between goods is high. When the HME dominates, trade liberalization will lead firms to concentrate in the larger market. This will decrease global emissions if the larger market has stricter environmental standards. In contrast, the HME is weak when markets are relatively similar in size. Hence it is the PHH that dominates firm location. Trade liberalization then leads firms to concentrate in the country with lower emission taxes leading to higher global emissions. Our analysis suggests that under monopolistic competition and intra-industry trade, trade liberalization between similar countries (of similar size) may increase global emissions while trade liberalization between dissimilar countries can decrease global emissions if the large country has a more stringent environmental regulation.

Interestingly, our results, derived in a model with intra-industry trade, imply a qualification of the results obtained by Copeland and Taylor (1995) where trade is inter-industry (between industries). They show how trade liberalization tends to increase global emissions if the income differences between the liberalizing countries are large, as dirty industries expand strongly in the poor country with low environmental standards. Our results show that market size also

environmental standards have resulted in an increase in imports from Mexico in dirty industries Levinson and Taylor (2008). At the same time, Japanese sector level data shows increased imports from developing countries in sectors that are mobile and face higher environmental regulation compliance costs Cole, Elliott, and Okubo (2010).

matters. If the rich country has a larger market, then the HME may induce firms to stay despite higher emission taxes and trade liberalization may therefore decrease global emissions even if there is a large income difference between the countries.

There is a large theoretical literature that analyses trade and emissions within a neoclassical framework or an oligopolistic strategic setting (see e.g. Copeland and Taylor (2004) and Rauscher (1997)). A relatively smaller literature analyses trade and the environment in models with monopolistic competition. Gurtzgen and Rauscher (2000) examine transboundary pollution in a monopolistic competition framework with two countries and find that tighter environmental policies at home can lead to reduced emissions abroad. However, in contrast to this paper, their model does not feature trade costs and the effects of trade liberalization can therefore not be analysed. Other papers have used trade and geography models to investigate the interplay of trade, agglomeration and emissions. Pfluger (2001) uses a trade and geography model, the footloose capital model, to include a disutility from local pollution to show that governments set inefficiently low emission taxes as trade costs fall – suggesting a pollution haven effect. Ishikawa and Okubo (2008) also use the footloose capital model to study the different impacts of environmental taxes and quotas for the location of firms as trade is liberalized. Zeng and Zhao (2009) use a trade and geography model with capital, land and labour where pollution harms the productivity of the agricultural sector. Their focus is on how trade liberalization affects the equilibrium location of footloose capital, and some of their results are driven by the HME, as in our model. Unlike Zeng and Zhao (2009), we use a standard one factor Dixit-Stiglitz model with a transboundary pollutant. We also differ from Zeng and Zhao (2009) by including firm abatement à la Copeland and Taylor (1994), which makes the model easily analytically tractable. Finally, we differ by introducing multiple manufacturing sectors in order to be able to focus on how sector level differences, e.g. in abatement technology and level of product differentiation, affect environmental outcomes.

2 The Model

This paper builds a two-country monopolistic competition trade model with multiple sectors and abatement costs. The focus of the discussion is how tax rate differentials interact with market size and thus tax rates are set exogenously.

2.1 Basics

There are two countries, home and foreign, denoted by $(j, m) \in (h, f)$, an A-sector and K individual M-sectors of manufactures denoted by $k \in (1, K)$. Each country has a single primary factor of production labour, L_j, used in the A-sector and the M-sector. The A-sector is a Walrasian, homogenous-goods sector, which is traded costlessly. M-sectors are characterized by increasing returns, Dixit-Stiglitz monopolistic competition and iceberg trade costs. M-sector firms face constant marginal production costs and fixed costs. Our model assumes that production by firms in the M-sector generates emissions of a transboundary pollutant. These emissions are a pure public bad in that emissions from any country affect welfare in both countries. Consumers in each nation have two-tier utility functions with the upper tier determining the consumer's division of expenditure among sectors and the second tier (CES) dictating the consumer's preferences over the various differentiated varieties within the M-sector.

All individuals in a country have the utility function:

$$U = C_M^{\beta} C_A^{1-\beta} - g(E_w), \quad where \quad C_M = \prod_{k=1}^{K} C_k^{\mu_k}, \tag{1}$$

where C_A is consumption of the homogeneous good, C_M is consumption of an aggregate of differentiated goods, $\beta \in (0,1)$, and the sector shares in consumption of differentiated goods, $\mu_k \in (0,1)$, sum to one, $\sum \mu_k = 1$. The function $g(E_w)$ captures climate damages and is a function of global emissions, which is the sum of emissions generated by the M-sectors in the home and foreign countries, $E_w = \sum_{k=1}^{K} (E_{h,k} + E_{f,k})$. Differentiated goods from each manufacturing sector enter the utility function through a sector-specific index C_k, defined by

$$C_k = \left[\int_0^{N_k} c_{ik}^{(\sigma_k - 1)/\sigma_k} di \right]^{\sigma_k/(\sigma_k - 1)}, \tag{2}$$

N_k being the mass of varieties in sector k in the country, c_{ik} the amount of variety i consumed in sector k, and $\sigma_k > 1$ the elasticity of substitution in sector k.

The A-sector is subject to constant returns to scale and perfect competition. The unit factor requirement of the homogeneous good is one unit of labour. This good is freely traded and since it is chosen as the numeraire

$$p_A = w = 1; \tag{3}$$

w being the nominal wage of workers in all countries. Income consists of wage incomes $Y = L$. Each consumer spends an overall share β of his income on manufactures, and the demand for a variety i in sector k is therefore

$$x_{ik} = \frac{p_{ik}^{-\sigma_k}}{P_k^{1-\sigma_k}} \mu_k \beta L, \tag{4}$$

where p_{ik} is the consumer price of variety i in sector k, Y is income, and

$$P_k \equiv \left(\int_0^{N_k} p_{ik}^{1-\sigma_k} di \right)^{\frac{1}{1-\sigma_k}}$$

is the price index of manufacturing goods in sector k.

Let us also account for the fact that manufacturing activity entails pollution in terms of emissions.[3] We follow Copeland and Taylor (1994) and assume that each firm i produces two

[3] We abstract from emissions related to the consumption of goods and only focus on supply-side emissions.

outputs: a manufactured good (x_i) and emissions (e_i). Governments in both countries use emission taxes (production taxes). The tax revenue is used to produce a public good outside of the model. A firm can reduce emissions by diverting a fraction θ_i of the primary factor, labor, away from the production of x_i. Firms pay the fixed overhead costs, and thereafter joint production is given by

$$x_{ik} = (1 - \theta_{ik}) \frac{l_{ik}}{a}, \tag{5}$$

$$e_{ik} = \varphi_{ik}(\theta_{ik}) x_{ik}, \tag{6}$$

where l_{ik} is labour demand by firm i in sector k, a is the labour input coefficient, and $0 \leq \theta_{ik} \leq 1$. Emission intensity ($e_{ik}/x_{ik}$) is determined by the abatement function

$$\varphi_{ik} = (1 - \theta_{ik})^{1/\alpha_k} \tag{7}$$

which is characterized by $\varphi_{ik}(0) = 1$, $\varphi_{ik}(1) = 0$, $\varphi'_{ik}(.) < 0$, and $0 < \alpha_k < 1$. $\frac{1}{\alpha_k}$ is a measure of the effectiveness of the abatement technology in sector k. Firms in each sector are symmetric in equilibrium, and we therefore drop subscript i from now on. Using (6) and (7) to substitute for θ_k in (5) yields

$$x_k = e_k^{\alpha_k} \left(\frac{l_k}{a} \right)^{1-\alpha_k} \tag{8}$$

from which we derive the variable cost function. Substituting out θ_k and with the fixed cost being sunk, we obtain the following cost function:

$$C_k = F + \kappa_k (wa)^{1-\alpha_k} t^{\alpha_k} x_k = F + \kappa_k t^{\alpha_k} x_k \tag{9}$$

where $\kappa_k \equiv \alpha_k^{-\alpha_k} (1 - \alpha_k)^{(1-\alpha_k)}$. We choose units of labour so that $a = 1$. t is the tax on emissions applied by the government. Profit maximization by a manufacturing firm in sector k and country j leads to consumer price

$$p_{jmk} = \frac{\sigma_k}{\sigma_k - 1} \tau_{jmk} \kappa_k t_j^{\alpha_k}, \tag{10}$$

in country m. Shipping the manufactured good involves a frictional trade cost of the "iceberg" form: for one unit of a good in sector k from country j to arrive in country m, $\tau_{jmk} > 1$ units must be shipped. It is assumed that trade costs are equal in both directions, $\tau_{jmk} = \tau_{mjk}$, and that $\tau_{jjk} = 1$, which allows us to drop the country subscript from trade cost, hence τ_k. The level of emissions for a firm in sector k is given by

$$e_k = \varphi_k x_k. \tag{11}$$

Thus, local emissions in country j from sector k are given by

$$E_{jk} = e_{jk} n_{jk}. \tag{12}$$

We note that emission intensity α_k, elasticity of substitution σ_k and trade costs τ_k are sector-specific parameters. With these sector-specific parameters having been established, we turn to analyse one representative M-sector and therefore omit the subscript k. Sectors can be analysed separately since the expenditure shares on each sector, μ_k, are constants.

2.2 Equilibrium

Firm profits in a sector are given by

$$\pi_h = \frac{\mu\theta}{\sigma}\gamma\kappa^{1-\sigma}\left(\frac{s}{\Delta_h}+\phi\frac{1-s}{\Delta_f}\right)t_h^{\alpha(1-\sigma)}-F \tag{13}$$

$$\pi_f = \frac{\mu\theta}{\sigma}\gamma\kappa^{1-\sigma}\left(\phi\frac{s}{\Delta_h}+\frac{1-s}{\Delta_f}\right)t_f^{\alpha(1-\sigma)}-F \tag{14}$$

where $\gamma \equiv \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}$ and $\phi = \tau^{1-\sigma}$. $s \equiv \frac{L_h}{L_h+L_f}$ and $1-s \equiv \frac{L_f}{L_h+L_f}$ are the income and expenditure shares in home and foreign, respectively. Without loss of generality, we set $L_h + L_f = 1$. Finally,

$$\Delta_h \equiv n_h p_h^{1-\sigma} + n_f \phi p_f^{1-\sigma} \tag{15}$$

$$\Delta_f \equiv n_h \phi p_h^{1-\sigma} + n_f p_f^{1-\sigma}. \tag{16}$$

Assuming free entry ensures that the equilibrium firm profits are zero. The operating profit, $px - MC \cdot x$, must then equal the fixed cost F. Price is a constant mark-up on the marginal cost, which yields the equilibrium scale of a firm in country j

$$x_j^* = \frac{F(\sigma-1)}{\kappa t_j^{\alpha}}. \tag{17}$$

Substitute (10), (15), and (16) into to equations (13) and (14), at zero profit, to obtain the equilibrium values for n_j

$$n_h = \frac{\mu\theta\left\{\left((1-s)\phi^2+s\right)T^{\alpha(\sigma-1)}-\phi\right\}}{\sigma F\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)}-\phi\right\}} \tag{18}$$

$$n_f = \frac{\mu\theta T^{\alpha(\sigma-1)}\left\{1-\left(1-\phi^2\right)s-\phi T^{\alpha(\sigma-1)}\right\}}{\sigma F\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)}-\phi\right\}} \tag{19}$$

where $T \equiv \frac{t_f}{t_h}$. The global number of firms in each sector is constant

$$n^w = n_h + n_f = \frac{\gamma\kappa\mu\theta}{\sigma F}, \tag{20}$$

a customary result of Dixit-Stiglitz models.

The model displays what Helpman and Krugman (1985) call a 'home market effect' (HME). That is, firms disproportionately locate to the larger market. The reason for this is that firms save on transportation costs by locating production closer to centres of demand, i.e. in the larger market. The HME is amplified by trade liberalization and may lead to the concentration of all manufacturing firms in the larger market for sufficiently low trade costs. To illustrate the HME, consider a case where the emission taxes of the home and foreign country are symmetric, $t_h = t_f$ $(T = 1)$. This gives the share of firms in the home country as a function of s and ϕ

$$s_n \equiv \frac{n_h}{n_f+n_h} = \frac{\left\{\left((1-s)\phi^2+s\right)-\phi\right\}}{(1-\phi)^2}. \tag{21}$$

Differentiating (21) with respect to s yields

$$\frac{ds_n}{ds} = \frac{1+\phi}{1-\phi} > 1. \tag{22}$$

As the relative size of home increases, the share of firms locating in home increases more than proportionately; this is the HME. Furthermore, as seen from (22), the steepness of $\frac{ds_n}{ds}$ increases in ϕ. Trade liberalization magnifies the HME.

2.3 Emissions and emission intensity

In country j, a firm's demand for emissions (as input to production) is derived by applying Sheppard's lemma on the cost function:

$$e_j = \frac{\partial C_j}{\partial t_j} = \alpha\kappa t_j^{\alpha-1} x_j, \tag{23}$$

which yields the emission intensity

$$\frac{e_j}{x_j} = \frac{\alpha\kappa}{t_j^{1-\alpha}}. \tag{24}$$

Substituting the firm's equilibrium output from (17) gives firm-level emissions:

$$e_j = \frac{\alpha F(\sigma-1)}{t_j}. \tag{25}$$

A higher emission tax and a more efficient abatement technology (lower α) decreases firms' emissions and emission intensity.[4] Total emissions from a sector in the two countries are given by

$$E_h = n_h e_h = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t_h} \frac{\left\{\left((1-s)\,\phi^2 + s\right) T^{\alpha(\sigma-1)} - \phi\right\}}{\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)} - \phi\right\}}, \tag{26}$$

$$E_f = n_f e_f = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t_f} \frac{T^{\alpha(\sigma-1)}\left\{1-\left(1-\phi^2\right) s - \phi T^{\alpha(\sigma-1)}\right\}}{\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)} - \phi\right\}}. \tag{27}$$

3 The effect of trade liberalization on emissions

The analysis juxtaposes the impact of a varying market size and asymmetric emission taxes. The size difference gives rise to an HME, while the difference in emissions taxes leads to a PHH effect. Before examining the interplay of these forces, we characterize the HME and the PHH separately. We continue to suppress the sector index, unless noted otherwise, because of the symmetry of sectors.

[4] Note that $\alpha\kappa = \alpha^{(1-\alpha)}(1-\alpha)^{(1-\alpha)}$, which increases in α.

3.1 Symmetric taxes

In this section, we constrain emission taxes to be symmetric in the home and foreign country, $t_h = t_f = t$, which negates the PHH. Isolating the HME means that trade liberalization will lead to a relocation of firms to the larger market. At the same time, note that equation (25) suggests that firm emissions are unaffected by ϕ. It follows from this that emissions will increase in the large market and decrease in the small one, as trade is liberalized. More precisely, the shift of production to the larger market entails a proportionate shift of emissions. Substituting $t_h = t_f = t$ into equations (26) and (27) yields

$$E_h|_{t_j=t} = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t} \frac{\{s(\phi+1)-\phi\}}{\{1-\phi\}}, \tag{28}$$

$$E_f|_{t_j=t} = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t} \frac{\{1-(1+\phi)s\}}{\{1-\phi\}}. \tag{29}$$

All firms, and therefore all emissions, end up in the larger market for sufficiently open trade ($\phi \geq \frac{1-s}{s}$). Note also that no relocation takes place if countries are exactly equal in size ($s = 0.5$), in which case each country generates half of global emissions.

The sum of equations (28) and (29) yields global emissions from a single sector

$$E^w|_{t_j=t} = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t}. \tag{30}$$

This suggests that when taxes are symmetric, global emissions from each sector decrease in the emission tax rate and abatement efficiency α. However, note that global emissions are independent of trade openness ϕ.

Proposition 1 *Trade liberalization leads to higher emissions in the larger market and lower emissions in the smaller market, but trade liberalization does not affect global emissions when environmental taxes are symmetric in the two countries.*

Proof: Differentiating the expressions (28) and (29) gives $\frac{\partial E_h}{\partial \phi} = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t}\frac{2s-1}{(1-\phi)^2}$ and $\frac{\partial E_f}{\partial \phi} = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t}\frac{1-2s}{(1-\phi)^2}$. It is seen from these expressions that $\frac{\partial E_h}{\partial \phi} > 0$ and $\frac{\partial E_f}{\partial \phi} < 0$ for $s > \frac{1}{2}$ and that $\frac{\partial E_h}{\partial \phi} < 0$ and $\frac{\partial E_f}{\partial \phi} > 0$ for $s < \frac{1}{2}$. Finally, it is seen directly from (30) that global emissions are unaffected by ϕ.■

Intuitively, since the global mass of firms and emissions per firm are unaffected by trade liberalization, it must be the case that global emissions are constant in ϕ.

3.2 Symmetric markets

Next we constrain market sizes to be identical in home and foreign ($s = \frac{1}{2}$), while we allow environmental taxes to vary. The identical market sizes isolates effects related to the PHH but negates the HME.

The relative mass of firms in the two markets now depends on the relative tax rates and the level of trade costs. Combining equations (18) and (19) yields the relative mass of firms in the home and foreign country

$$\left.\frac{n_h}{n_f}\right|_{s=\frac{1}{2}} = \frac{\left(1+\phi^2\right) T^{\alpha(\sigma-1)} - 2\phi}{1+\phi^2 - 2\phi T^{\alpha(\sigma-1)}}. \tag{31}$$

Note first that when $T = 1$, i.e. a totally symmetric economy, the expression reduces to $\frac{n_h}{n_f} = 1$. From (31), the condition for there being manufacturing firms in both countries is

$$\frac{2\phi}{1+\phi^2} < T^{\alpha(\sigma-1)} < \frac{1+\phi^2}{2\phi}. \tag{32}$$

The range of relative taxes, T, for which there are firms in both countries varies with the level of trade costs. Firms are active in both countries for any $T > 0$ in autarky ($\phi = 0$), but the range shrinks as trade is liberalized. The range collapses to $T = 1$ for free trade ($\phi = 1$). Any tax difference would lead all firms to relocate to the low tax country when trade is free.

Differentiating (31) with respect to T yields the change in the location of production for a change in the relative tax rate

$$\left.\frac{\partial\left(\frac{n_h}{n_f}\right)}{\partial T}\right|_{s=\frac{1}{2}} = \frac{\alpha\left(\sigma-1\right) T^{\alpha(\sigma-1)-1}\left(1-\phi^2\right)^2}{\left(2\phi T^{\alpha(\sigma-1)} - 1 - \phi^2\right)^2} > 0. \tag{33}$$

Thus, a relative decrease in the tax rate of the home country leads to an increase in the share of firms in the home country. This identifies a pollution haven effect: firms are drawn to countries with low environmental standards.

The effect of trade liberalization on the location of production is obtained by differentiating (31) with respect to ϕ :

$$\left.\frac{\partial\left(\frac{n_h}{n_f}\right)}{\partial \phi}\right|_{s=\frac{1}{2}} = -\frac{\left(1-\phi^2\right)\left(1-T^{2\alpha(\sigma-1)}\right)}{\left(2\phi T^{\alpha(\sigma-1)} - 1 - \phi^2\right)^2} > 0 \text{ for } T > 1. \tag{34}$$

This shows that trade liberalization leads more firms to locate in the low tax country (in this case the home country). This is the PHH.

Proposition 2 *The country with the lower tax rate has the larger share of firms when markets are symmetric.*

Proof: The proposition follows directly from (33).■

Proposition 3 *Trade liberalization leads to a relocation of firms to the low tax country when markets are symmetric.*

Proof: The proposition follows directly from (34).■

We now turn to analysing how the relocation of firms affects emissions. Emission levels in the home and the foreign country when markets are symmetric are obtained by setting $s = \frac{1}{2}$ in equations (26) and (27). This yields

$$E_h|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t_h}\frac{\left\{\frac{1}{2}\left(\phi^2+1\right)T^{\alpha(\sigma-1)}-\phi\right\}}{\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)}-\phi\right\}}, \tag{35}$$

$$E_f|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1)\mu\theta}{\sigma t_f}\frac{T^{\alpha(\sigma-1)}\left\{1-\frac{1}{2}\left(1-\phi^2\right)-\phi T^{\alpha(\sigma-1)}\right\}}{\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)}-\phi\right\}}. \tag{36}$$

Emissions are higher in a low tax country when market sizes are symmetric. This is a consequence of firstly, firms migrating to the the country with a lower emission tax (the PHH), and secondly that firms pollutes more when the tax is lower (see equation (25)).

Global emissions E^w from the sector are found by summing (35) and (36). To characterize the change in global emissions with trade liberalization, we differentiate E^w with respect to ϕ :

$$\left.\frac{\partial E^w}{\partial \phi}\right|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1)\mu\theta}{2\sigma t_h t_f}\frac{T^{\alpha(\sigma-1)}\left(1-\phi^2\right)\left(T^{2\alpha(\sigma-1)}-1\right)\left(t_f-t_h\right)}{\left(\phi T^{\alpha(\sigma-1)}-1\right)^2\left(T^{\alpha(\sigma-1)}-\phi\right)^2} > 0. \tag{37}$$

The sign of this expression does not depend on the sector-specific parameters (α, σ, τ), which means that trade liberalization increases emissions across all K manufacturing sectors.

Proposition 4 *Trade liberalization leads to higher global emissions if environmental taxes differ between countries and markets are symmetric.*

Proof. The proposition follows directly from (37).■

Trade liberalization makes it easier for firms to concentrate in the low tax country, and since the global mass of varieties is always constant, it must be the case that trade liberalization leads to more emissions; that is, we have a pollution haven. This result is congruent with the neoclassical analysis (see Copeland and Taylor (2004)).

3.3 The general case

We now turn to the case where both market size and taxes differ between the two countries: both s and T are unconstrained. Global sector-level emissions are found by summing equations (26) and (27) to obtain

$$E^w = \frac{\alpha(\sigma-1)\mu\theta}{\sigma}\frac{1}{t_f}\frac{T\left\{\left(\left(1-s\right)\phi^2+s\right)T^{\alpha(\sigma-1)}-\phi\right\}+T^{\alpha(\sigma-1)}\left\{1-\left(1-\phi^2\right)s-\phi T^{\alpha(\sigma-1)}\right\}}{\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)}-\phi\right\}}. \tag{38}$$

The change in global emissions from a change in trade openness is given by

$$\frac{\partial E^w}{\partial \phi} = \alpha(\sigma-1)\mu\theta T^{\alpha(\sigma-1)}(T-1)\frac{\left(s\left(T^{\alpha(\sigma-1)}-\phi\right)^2-(1-s)\left(T^{\alpha(\sigma-1)}\phi-1\right)^2\right)}{\sigma t_f(1-\phi T^{\alpha(\sigma-1)})^2(T^{\alpha(\sigma-1)}-\phi)^2}. \tag{39}$$

The effect of trade liberalization on global emissions is in this case determined by the interplay of the two forces that have been discussed so far; the HME and the PHH.

Consider the case where the larger country has the lower emission tax ($s > \frac{1}{2}$ and $T > 1$). In this setting, trade liberalization induces firms to move to the large market (the HME) and so does the lower tax on emissions (the PHH). Trade liberalization will therefore lead to a larger share of firms in the large low tax country, and consequently to higher global emissions.

Proposition 5 *Trade liberalization leads to an increase in global emissions if the larger market has lower emission taxes.*

Proof. $\left(T^{\alpha(\sigma-1)} - \phi\right)^2 \geq \left(T^{\alpha(\sigma-1)}\phi - 1\right)^2$ for $T > 1$, and $s > (1-s)$ for $s > \frac{1}{2}$. The numerator in (39) is therefore positive, which implies that $\frac{\partial E^w}{\partial \phi} > 0$.■

However, the effect of trade liberalization is ambiguous when the larger country has the higher emission tax ($s > \frac{1}{2}$ and $T < 1$). In this case, the HME and the PHH counteract each other; firms would prefer to escape the higher tax in the large market (the PHH), but they are at the same time drawn to the larger market because of the HME. The effect of trade liberalization on the location of production and on global emissions therefore depends on the relative strength of the HME and PHH; trade liberalization will decrease global emissions when the HME outweighs the PHH effect. The dominant force is determined by relative country size, relative taxes and trade costs. For example, the HME is increasing in market size asymmetry. As an extreme case, evaluate equation (39) at $s = 1$ and $T < 1$. This yields $\frac{\partial E^w}{\partial \phi} < 0$, implying that trade liberalization decreases global emissions.

Figures 1 and 2 plot (38) and (18) in two cases, when the large home country has higher emission taxes,[5] that is, when the HME and the PHH counteract each other.

[5] The parameters used to plot Figure 1 are $\sigma = 6, \mu = 0.5, \alpha = 0.7, t_h = 0.35, t_f = 0.3, s = 0.7, F = 0.1$ and likewise Figure 2 is plotted with $\sigma = 2, \mu = 0.5, \alpha = 0.7, t_h = 0.35, t_f = 0.3, s = 0.7, F = 0.5$.

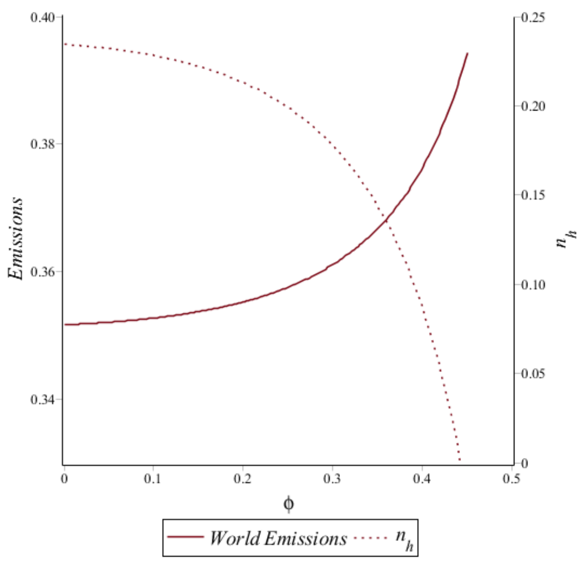

Figure 1: Trade liberalisation increases global emissions.

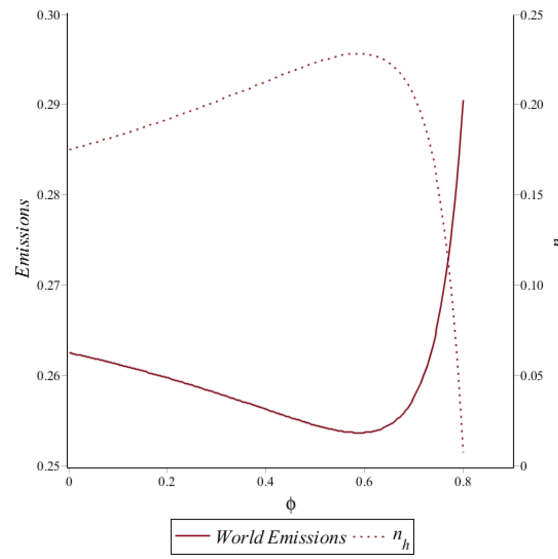

Figure 2: A U-shaped relationship between trade liberalisation and global emissions

The HME is always dominated by the PHH in Figure 1, leading to a monotone increase in global emissions, as trade is liberalized. Firms continuously move to the lower tax country as trade is liberalized and this increases global emissions. Remember that the global mass of firms is constant and that firm emissions are independent of ϕ. A movement of firms from the high tax home country is a sufficient condition for increased global emissions.

Figure 2 on the other hand illustrates a case where the HME dominates the PHH for a range of trade costs, although this dominance switches as trade costs fall sufficiently. Here, we have a U-shaped relationship between trade costs and global emissions. As trade is liberalized, starting from autarky, global emissions are reduced as firms are drawn to the larger high tax country. However, as trade is further liberalized, the pattern is reversed and global emissions then increase as we approach free trade. This effect follows from the well established property of the HME: the strength of the HME is hump-shaped in trade costs and is strongest for intermediate trade costs. When trade costs are high, there is little trade and thus little incentive for firms to locate in the large market and export to the smaller market to save on trade costs. On the other hand, with low trade costs, firms have no incentive to avoid trade costs. Thus, the HME is U-shaped in ϕ. Trade liberalization therefore first leads to lower emissions as the HME grows stronger, and more firms are drawn to the high tax economy. However, when trade liberalization reaches the point where the HME weakens, further liberalization induces firms to move away from the large high tax country, which increases the emissions.

It is possible to distinguish the two cases by noting that E^w (by equation (38)) is a second-order polynomial in ϕ. We can determine if we are in the case shown by Figure 1 or in the case shown by Figure 2 by evaluating $\frac{\partial E^w}{\partial \phi}$ at $\phi = 0$. Trade liberalization increases global sector level emissions, as in Figure 1, if the derivative evaluated at $\phi = 0$ is positive. Likewise, a negative derivative implies that global emissions are U-shaped in ϕ. The condition that distinguishes the cases is given by the following proposition:

PROPOSITION 6 *Global sector level emissions are U-shaped in trade freeness when* $T^{2\alpha(\sigma-1)} < \frac{1-s}{s}$*, and increase monotonically in trade freeness when* $T^{2\alpha(\sigma-1)} > \frac{1-s}{s}$.

Proof: The proposition follows from substituting $\phi = 0$ in (39).■

Trade liberalization decreases emissions when the home country is sufficiently large relative to the tax difference. The threshold between the U-shaped and monotonically increasing global emissions is a function of the sector-specific parameters σ and α. Trade liberalization is more likely to increase emissions in sectors with a high σ, since a higher σ implies that goods are closer substitutes, which decreases the importance of the HME. Second, a higher α (a less efficient abatement technology) increases the likelihood that trade liberalization increases emissions, since it makes firms more sensitive to the emission tax, which implies that a larger difference in size is needed to compensate firms for the higher tax in the larger market.

Our results have several implications for empirical studies of the PHH. In particular, they suggest that relative market size, trade costs, ease of abatement, and the substitutability of goods may need to be considered in the design of the estimated equation.

4 Concluding remarks

This paper uses a monopolistic competitive framework with many sectors to study the impact of trade liberalization on local and global emissions. We focus on effects stemming from tax differences (PHH) and the differences in market size (HME) and exclude comparative advantage effects derived from differences in factor intensities; our model only has one factor of production.

We begin the analysis by examining the home market effect and the effect of asymmetric emission taxes separately. We find that trade liberalization does not affect global emissions if taxes are identical in the two countries. In this setting, the home market effect induces firms to locate to the larger market which, in turn, implies higher emissions in the larger market and lower emissions in the small market; however, global emissions remain constant. On the other hand, when countries are symmetric in size but emission taxes differ, trade liberalization increases global emissions. This result is driven by the pollution haven effect.

We then analyse the general case, relaxing the constraints on market size and emission taxes. Trade liberalization increases emissions when the HME and the PHH reinforce each other. This is the case when the larger country has a lower emission tax. As trade is liberalized, both the HME and the PHH draw firms to the larger market which results in higher global emission. However, trade liberalization may not result in increased global emissions when the HME and the PHH work against each other. This happens when the larger country has a higher emission tax. If the HME dominates the PHH, then trade liberalization will result in a decrease in global emissions as firms are drawn to the large, high tax economy. It is not uncommon that a large country liberalizes trade with a smaller market with a laxer environmental standard. The fact that some studies fail to identify PHH effects, could be due to the fact that the market under study is large enough to overcome the PHH , e.g. in the case of U.S. and Mexico.

Generally, our results suggest that the relative market size, the level of trade costs, the ease of abatement, and the degree of product differentiation at the sectorial level are relevant variables for empirical studies on trade and pollution.

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